## Presentation to Prof. A. Hutchinson, F.R.S., Emeritus Professor of Mineralogy in the University of Cambridge.

ON the retirement of Professor A. Hutchinson from the Chair of Mineralogy at Cambridge, at the end of the academical year 1930–1, it was felt by those associated with him in the Department that his services during thirty-five years as Demonstrator, Lecturer, and Professor should be commemorated in some special manner. A subscription was instituted amongst his former pupils, and Sir William Rothenstein kindly undertook the execution of a portrait in oil.

At a gathering in the Library of the Department on Saturday, 12th March, Dr. Herbert H. Thomas, in making the presentation on behalf of the subscribers, referred to Professor Hutchinson's original researches and to the inspiring character of his teaching. The Professor, in expressing his thanks, gave an interesting sketch of the history of the Department during his time, enumerating many eminent men of science who had been his pupils. He also paid tribute to the help he had received from the members of the staff and from the laboratory assistants past and present.

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# ORIGINAL ARTICLES.

## Some Problems of the Pleistocene Hydrography of Kharga Oasis, Egypt.

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(PLATES XXVI–XXXI.)

### Introduction.

FOR the past two winters it has been the author's good fortune to undertake the geological work for Miss Caton-Thompson's investigations into the prehistory of Kharga Oasis. This necessarily involved a close consideration of the water supply in Pleistocene times, the results of which disclosed some interesting new facts and raised climatic questions of more than local interest.

The author gratefully acknowledges financial help from grants from Section " C " of the British Association and the Gloyne Fund of the Geological Society. She would further like to thank Mr. O. H. Little, Director of the Geological Survey of Egypt, for much assistance both in the field and in Cairo throughout the two seasons.

### General Physical and Geological Features of the Oasis.

Some knowledge of the present physical and geological conditions of the oasis is necessary to understand the water supply problems—these will now be briefly considered. Detailed accounts can be found in Dr. John Ball's (1)[1] and Mr. H. J. L. Beadnell's (2) books on this region. All workers in the Libyan desert owe a debt of gratitude to these two great pioneers who have done so much towards a fundamental understanding of desert geology and hydrography. If the author's work does not always bear out some of their conclusions, this is a natural result of detailed investigation of a period which necessarily received little study in rapid, preliminary surveys without which more specialized later work would have been impossible.

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[1] The figures in parentheses refer to the Bibliography at the end.

The Kharga Oasis, lying between latitudes 24° and 26° N., is an elongated depression some 185 kilometres from north to south and about 80 kilometres wide, sunk 300–400 metres below the level of the Libyan plateau (Fig. 1). It is separated from the Nile Valley by 140 kilometres of this plateau, generally acknowledged to be one of the most waterless and desolate tracks in the world. The eastern and northern boundaries are sharply delimited by steep scarps, capped by Eocene or Cretaceous limestone. On the south and west there is a gradual rise to the general level of the Sahara. The floor of the depression is composed of Nubian sandstone and clay, the sandstone cropping out mainly in the north and west. This sandstone, which is a white or variegated, unfossiliferous current bedded rock, is known as the Upper or Surface Water Sandstone, from the fact that 120 metres below it—separated by impermeable grey clays—is another sandstone—the Artesian Water Sandstone—from which all the present water supply of the oasis is obtained by deep bores.

The Nubian clays—red or grey—pass up at the foot of the eastern scarp into an alternating series of thin limestones and clays crowded with *Exogyra overwegi*. This *Exogyra* Series is followed by Ash Grey Shales, above which is a thick development of white chalk with *Ananchytes*. The latter frequently forms a conspicuous plateau 150 metres below the main eastern scarp, its surface, 5–6 kilometres broad, being deeply entrenched by vertical-sided wadis. Above the chalk is another alternating series of green shales and white marls—the Esna Shales—these are followed by Lower Eocene limestones and marls, the rock forming the top of the scarp and the Libyan plateau being a hard, crystalline nummulitic limestone weathering into numerous holes giving it a distinctive "honeycomb" effect. Sections across the oasis showing the relation of these beds can be examined in both Dr. Ball's and Mr. Beadnell's books. Suffice it to say here that the whole series has a low easterly dip and that there is a line of disturbance—fault or monoclinal fold—down the centre of the depression, with which are associated circular rock structures, called by Beadnell "centroclinal".

There is, additionally, according to the author's interpretation, a marked southerly pitch of the Nubian Series in an area north-east of Kharga to be described later; but the absence of fossils and distinctive horizons of any kind make the interpretation of structure a difficult matter in this region. Dr. Ball maps small local faults along the scarp, and Mr. Beadnell shows an anticlinal fold at its foot, but there is no evidence that the scarp itself is due to faulting; it appears to be entirely an erosional feature.

The present climate is that of a true desert—the rainfall is negligible, the air very dry—only a fourth the amount of moisture of the air of Cairo—the temperature averages 5° C. higher than at Cairo, the pressure 7–8 mm. lower. The wind is predominantly north or north-north-westerly, and blows with varying force five days out of six.

## PRESENT WATER SUPPLY.

The oasis to-day exists solely as such by reason of the artesian supply obtained from the deep-seated sandstones. Were this to fail all the floor of the depression would relapse into the desert which already occupies far the greater part of it. There are, however, rare natural high-level springs, which, together with a certain amount of seepage from the Surface Water Sandstones, would allow (and probably always have allowed) the depression to be used as a watering place for passing caravans. The best known of these springs is Ain Amur in the north-west, but Dr. Ball mentions one on the eastern scarp nearly opposite Beris, the chief southern village. (Text-fig. 1.) It is a small spring of clear but rather salty water, lying 110 metres below the top of the plateau and 180 metres above Beris. Dr. Ball thinks all the high-level springs are supplied by surface water accumulating in the limestones.

## PLEISTOCENE HYDROGRAPHY.

### *A. Of the Eastern Scarp.*

It has long been known that in past times the eastern scarp enjoyed a better climate than it does to-day, with sufficient rainfall to support the growth of trees and to give rise to the deposition of tufa down the scarp slopes. Leaves and shells were collected from these deposits by Zittel (3) when accompanying Rohlf's expedition in 1873–4. He identified one leaf as *Quercus ilex*, a native of southern Europe, and a reed as *Arundo.*

#### *Distribution of Tufa.*

On Dr. Ball's geological map (scale 1 : 500,000) three big tufa outcrops are marked, and one small one at Refuf. All are on the eastern scarp, and all provide routes up the otherwise almost unscaleable slopes. The outcrops range from latitude 25° 6′ to 25° 55′ in the extreme north-eastern corner of the depression. There are, however, many smaller outcrops (too small to be shown in Dr. Ball's map) either forming promontories, or perched on the watersheds between the modern wadis. These are particularly numerous between the big outcrop at Bulaq Pass (latitude 25° 17′) and the small one at Refuf 45 kilometres to the north. From Refuf northward till the big north-easterly outcrop is reached, there is little or no tufa, though occasional tufa pebbles are found in the wadis adjacent to Refuf. The tufa is also strangely absent from the high scarps of the north and north-west, and also from the eastern scarp south of latitude 25° 6′. It is hoped to discover the significance of these facts next season; it may be that small outcrops once existed, but have been entirely denuded, in which case traces of them should be found in the gravels which are everywhere such a conspicuous feature of the wadis and lower slopes of the scarps. Tufa is not found in or around any of the isolated hills in the oasis, either the two conspicuous outliers of the eastern scarp, or the lower hills north of Kharga village.

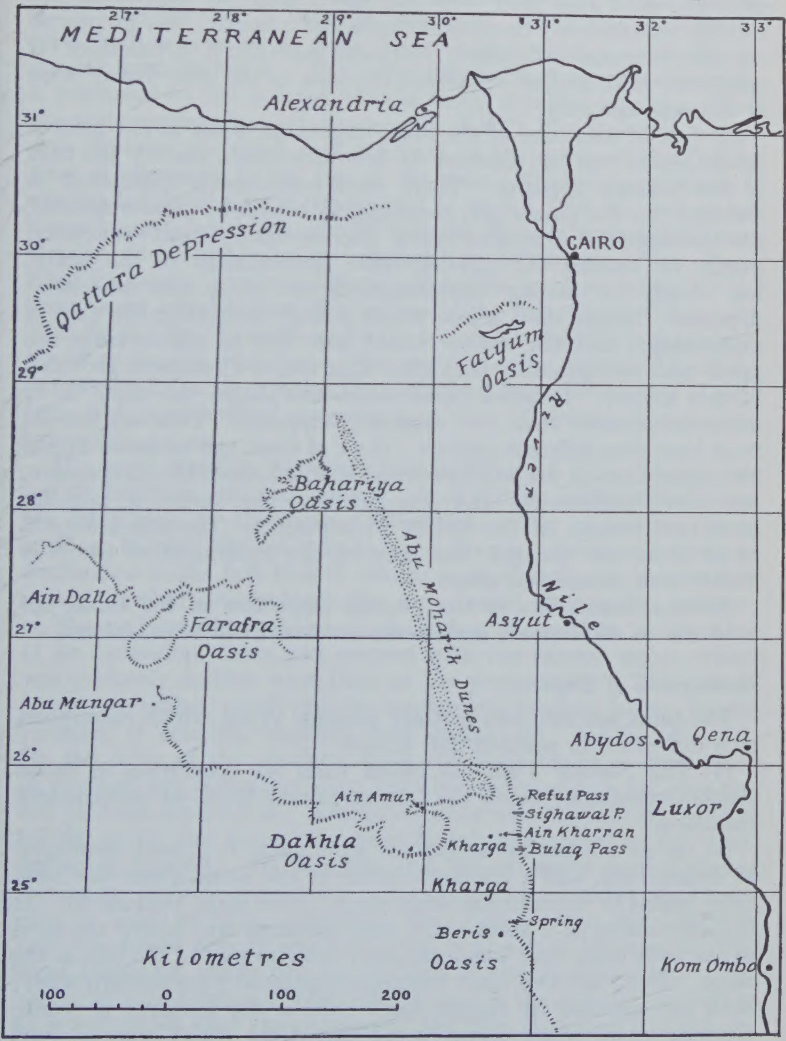

Fig. 1.—General Map of the Western Desert.

### *Age of Tufa.*

Dr. Ball mapped the tufas as Pleistocene, mainly because their positions show that they were laid down after the depression had reached substantially its present depth and breadth ; but no precise dating evidence was obtained. In recent years Dr. K. S. Sandford (4) concluded that similar calcareous deposits in the Nile Valley were of Pliocene age only.

In view of this, one of the most important items in the present investigation was the attempt to determine more exactly the date of the Kharga deposits. There were considerable difficulties in the way, for the plants are, according to botanists, indeterminable, and the shells are all modern types. Success was obtained eventually, partly by tracing the physiographic development of the scarp, but chiefly by finding implements in the tufas and associated deposits. This is, then, a case where geology is much in the debt of archaeology, and the author would here like to acknowledge the great and indispensable help that Miss Caton-Thompson provided in this matter. Detailed examination has shown the story to be more complicated than was originally supposed. Tufa has formed in at least *four* different periods ; three of these can be dated by the associated tools to the late Lower and Middle Palaeolithic (Acheulean, Acheuleo-Levalloisean, and Pre-Sebilian—the latter a peculiar local modification of the Middle Palaeolithic). The oldest deposit of all is as yet undated, but may be the equivalent of the Nile Valley tufa mentioned above.

After a description of the general characters of the tufas, the evidence on which these statements are based will be examined.

### *Description of Tufas.*

The tufas fall into two distinct physical types, which correspond to a difference in position and in age.

(1) *The Plateau Tufa*—so called from its occurrence in broad sheets immediately below the Libyan plateau level—is undoubtedly the oldest.

So far as present investigations have gone, it is best developed at Bulaq Pass, half a kilometre south of the point where the Esna road begins to descend the scarp slope. (See map, Text-fig. 2.) It is recognizable as a great black mass standing well above the level of the later tufas over which the road finds its way to the foot of the slope. There are two main outcrops, separated by a modern wadi ; both are bounded by rugged black cliffs at the southern or south-western ends, below which is an incredibly rough scree-covered slope. They are both joined to the main plateau by narrow necks of Eocene rock at R.L. 346, 359 m.[1] for the north and south outcrops respectively (see map). The highest level is found on the southern outcrop at R.L. 376 m., where a big beacon has been erected by the

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[1] Reduced level above sea at Alexandria.

Topographical Survey, who kindly supplied its height. The northern outcrop rises to R.L. 370 m., and in both cases the tops of the cliffs mentioned above are approximately R.L. 368 m. The Eocene plateau to the east is between 380–90 m., while the floor of the deep wadi separating it from the southern outcrop is at 305 m. not far from its head. The wider extension of this tufa formerly is witnessed by the isolated hillocks in the tumbled ground north of the north outcrop (see left distance, Pl. XXVI, Fig. 2), and in a small area between the track and the wadi to the south of it 1,500 m. west of the cairn at the top of the pass. This outcrop which is surrounded by the later (wadi) tufa is at R.L. 252 m., and unless it is a large fallen block, shows that the Eocene surface had been already considerably eroded before its deposition. The downward limits are, however, almost impossible to trace owing to the great scree development at the base of the tufa slopes. (See map, Text-fig. 2.) For the same reason its thickness is difficult to determine, but it appears to vary from a few metres on the eastern side of the outcrop to 10 m. or more on the cliff faces, but whether this is solid tufa or is a superficial covering to a core of Eocene limestone is impossible to see.

The most striking physical characteristics of this plateau tufa are its hardness and massiveness. It is further distinguished from the later type by the intense blue-black colour of the weathered surface, though the fracture is light brown. Another important distinction is the fact that it always rests directly on the country rock ; further interbedded silts are absent, though the presence of Eocene limestone pebbles on its surface shows that, at the time of its formation, there was contact with the eastern scarp, which was probably further west than at the present day. The surface is very irregular, partly due to mechanical erosion, partly to the presence of solution channels and basins (Pl. XXVI, Fig. 1). On the sides of the channels, dark and light bands, a centimetre or so thick, are commonly seen, but the nature of this banding has not yet been determined. Except for a few reed impressions, neither leaves, shells, nor tools have been found, and therefore no exact dating is possible. Its position and the extensive erosion it has undergone indicate a great age ; it is hoped that further work may give a clue to this. Outside the Bulaq area the plateau tufa was found only in small outcrops near Um el Ghenneiem, the most southerly of the two big outliers of the Eocene scarp. The character and relation to the country rock is the same as at Bulaq. It is noticeable that the outlines of the hills on which it rests are particularly rough and uneven compared with those capped by the later tufa.

To sum up, the plateau tufa is an ancient, hard, massive, high-level deposit, practically devoid of life. It rests directly on the Eocene. It would seem to be closely comparable to the "lithoid" tufas of Lake Lahontan and other areas notably on the Bahia plateau in Brazil (see p. 397), where a hard massive tufa rests on the country rock and is cut through by the modern wadi system.

(2) *Wadi Tufas.*—These Palaeolithic tufas form the bulk of the deposits examined on the eastern scarp between Bulaq and Refuf

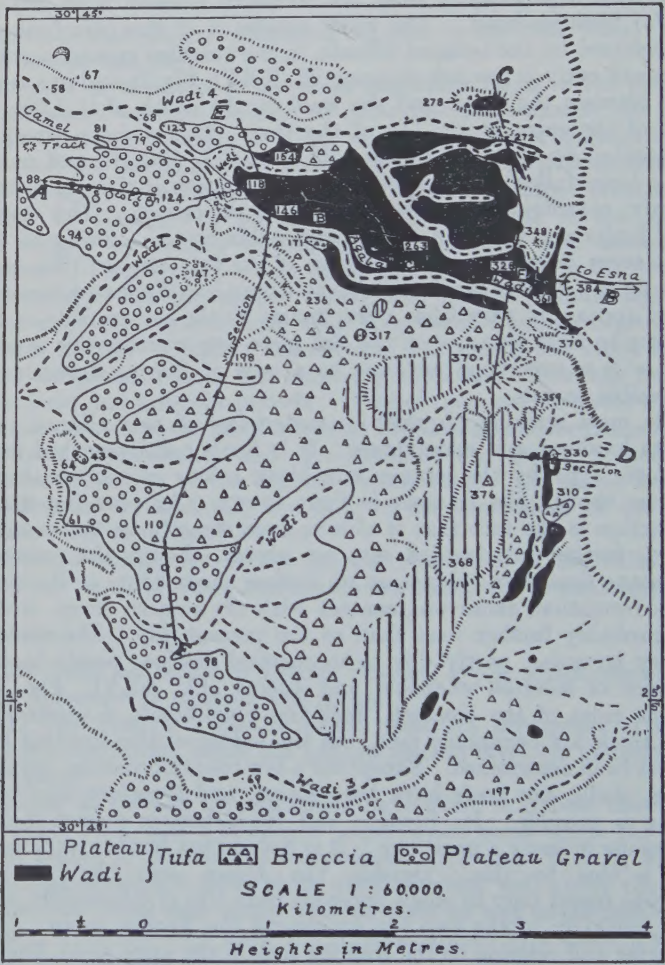


Fig. 2.—Map of Tufa Deposits of Bulaq Pass.

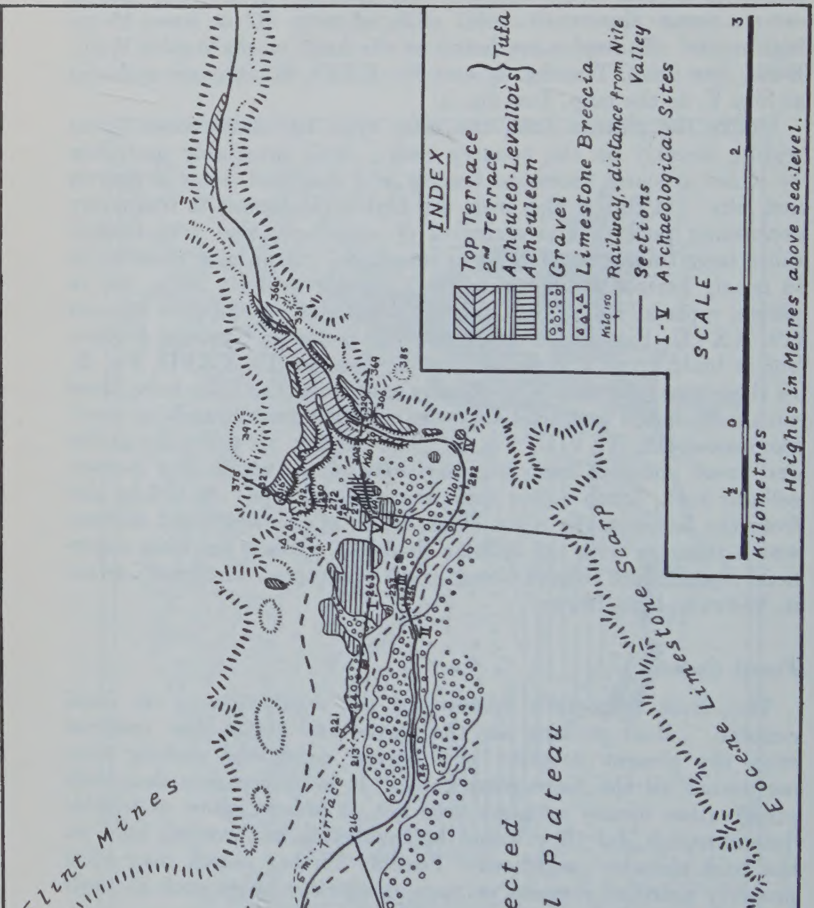
Passes. They invariably lie at a lower level than the plateau type, and have been laid down in valleys cut after the formation of the plateau tufa. The variation in level ranges from R.L. 361 to 318 at Bulaq and 342 to 254 m. above sea level at Refuf. The thickness is also very variable, the average is 2–3 m., but in certain areas apparently solid cliffs of tufa 10 or even 15 m. high occur. Examples are found at the head of the Aqaba Wadi, Bulaq (see map, Text-fig. 2, and Pl. XXVI, Fig. 2), and at Refuf at Site V, on the map, Text-fig. 3.

Unlike the plateau tufa, the later type has never been found resting directly on the country rock; it is invariably underlain by either a coarse limestone breccia or a stratified series of gravels and silts. It differs also from the high-level deposit in frequently containing pockets and stringers of white silt, and may enclose quite large fragments of chert or limestone. Over wide areas it lies in nearly horizontal sheets or has a regular westerly slope, but in places, especially at Refuf, it forms a series of conspicuous terraces (Pl. XXVII, Fig. 1). The terrace edge is not an erosional feature, but is built up of a series of curving laminæ (Pl. XXVII, Fig. 2). In these cases the tufa is frequently cavernous, the holes being lined with mamillated or stalactitic forms, or with great branching coral-like masses (Pl. XXVIII, Fig. 1). The laminae are generally harder and more compact than the horizontal tufa, which is a porous, cellular rock, much softer than the plateau type. It differs also from the latter in the rusty black colour of the weathered surface, which, together with the cellular character, gives it the close superficial resemblance to lava noted by all observers. The fresh surface is, however, light brown.

### *Fossil Content.*

The most important feature of the wadi tufa is its fossil content. Most striking are the leaves and stems, the contrast with the present desolate and barren conditions making their occurrence all the more remarkable. It is unfortunate that their preservation merely as casts does not at present allow of reliable determination, for they would be invaluable in throwing light on the past climatic conditions. Possibly further search may yield properly petrified remains or more distinctive parts such as seeds or fruits.

It is, however, certain that at least seven different kinds are represented; one is a fern, one a parallel-veined leaf, another strap shaped, another palmately veined. Reeds predominate, and are frequently much thickened by calcareous accretion. In some cases they stand erect, often they are drifted, broken fragments. In one instance the cross section of a stem was triangular instead of round, and may possibly be the mould of a sedge instead of a reed. The most abundant leaf is of the "ilex" type; the leaves are generally scattered at all angles through the deposit, but in one case (at Kilo 149 at Refuf) a fairly regular alternation of leaf and tufa layers was noted, the tufa being in the form of vertical beaded chains (Pl. XXVIII, Fig. 2). The different types of leaves are apparently uniformly


Flint Mines
Dissected Gravel Plateau
Eocene Limestone Scarp
5 m. Terrace
White Chalk
Kilo 150
INDEX
Top Terrace
2nd Terrace
Acheuleo-Levallois
Acheulean
Tufa
Gravel
Limestone Breccia
Railway, distance from Nile Valley
Sections
I-V Archaeological Sites
SCALE
1 ½ 0 1 2 3
Kilometres
Heights in Metres above Sea-level.
I
II
III
IV
V
360
331
385
369
306
329
347
327
378
292
272
278
282
263
240
221
213
216
199
192
241
237
200
171
283

distributed along the scarp, but in any one outcrop they tend to be more abundant in the higher deposits.

The shells proclaim the change in the past conditions as surely as the leaves, though the great adaptability of mollusca makes the interpretation of these conditions difficult. On the floor of the depression a few common Egyptian gasteropods are found in irrigation channels, past or present, but neither there nor on the scarp have any living land shells been recorded. In the wadi tufas and their associated deposits the land shell *Pupa* has long been known to occur but the present investigations have added seven more. Eight species of freshwater gasteropods were also found. It is a remarkable fact that *all* the shells in these deposits are, without exception, univalves, there is not a single example of a bivalve. The following is a list of all the species found up to date; the author is greatly indebted to Major M. Connolly and Mr. J. R. le B. Tomlin for the identification of the land shells.

*Land Shells.*

EGYPTIAN.

*Pupoides* (*Leucochiloides*) *sennaaricus* Pfeiffer.
*Vallonia pulchella* Müller (introduced at present day).
*Zootecus insularis* Ehrenberg.

PALAEARCTIC.

*Euconulus fulvus* Müller.
*Vallonia excentrica* Sterki.
*V. pulchella* Müller.
*Vertigo antivertigo* Drap.

CENTRAL AFRICAN.

*Gasterocopta insula* Preston.
*Pseudopeas saxatile* (Morelet).

*Freshwater Shells.*

*Hydrobia peraudieri* Bgt.
*Limnaea caillaudi* Bgt.
*Melanoides tuberculata* (Müll.).
*Planorbis alexandrinus* Ehrb.
*P. ehrenbergi* Beck.
*P. mareoticus* (Let.) Innes.
*Succinea cleopatrae* Pallary.
*Segmentina angusta* Jickeli.

The remarkable present distribution of the land shells is shown in the list; whatever it may mean climatically it indicates clearly that faunal migration in the Pleistocene was much easier than at present. A similar conclusion was reached in a study of the Faiyum Pleistocene freshwater shells. A discussion of this unique fauna will be deferred till after another season.

The assemblages found in the various localities are slightly different, but further work is necessary to determine whether this is due to the chances of collecting, or whether the European and tropical elements entered at different times and places.

The freshwater shells are less interesting. They are all common Egyptian types: the only one requiring special mention is *Hydrobia peraudieri*, a brackish water form, which probably indicates the existence of salty pools on the wadi floors during the dry seasons.

The land and freshwater forms occur together in the silts and in the tufa. They lie at all angles and in all positions, and have obviously been washed down from the higher levels with such rapidity that no sorting could take place. In one instance at the foot of the highest terrace at Refuf a carbonaceous layer containing nothing but land shells was found ; this may possibly represent an actual land surface. Many of the shells both in the tufa and in the underlying silts are heavily coated with lime, but they are associated with a larger number which are not. It is to be noted here that no oolites or pisolites were observed in any of the deposits.

### *Mode of Origin of Tufas and Comparison with Modern Conditions of Formation.*

The deposition of tufa necessarily indicates that the waters of the eastern scarp were heavily charged with lime, and the question at once arises as to how this took place. Any rain at the present day runs off and is evaporated so quickly that its lime content must be very small, and tufa formation is now therefore an impossibility. In this connection the source of the water must be considered—was it *all* derived from rain, or was it in part or entirely due to springs issuing in times past in greater numbers along the scarp ?

Mr. Beadnell (op. cit., p. 112) has suggested the latter explanation and in favour of it is the very sporadic distribution of the tufa. Dr. Ball (op, cit., p. 91) gives evidence to show that at Bulaq Pass the calcareous water from the plateau drained into a gully, depositing tufa on the sides and floor (Pl. XXVI, Fig. 2). In the photograph a man stands at the top of the 11-metre tufa cliff that falls sheer to the wadi below. Above him are horizontally bedded tufa and silt deposits 4 m. high. The wadi is named Aqaba Wadi on the map, and is the one referred to by Ball as just south of the track. It is cut, as frequently happens, along the line of weakness between the wadi tufa (seen in the middle distance) on the right or north and the Eocene marls and shales (middle distance on the left). The hillocks on the left horizon are those outliers of plateau tufa referred to on page 391.

Here, then, there can be no doubt that the tufa is derived in part from run off, and this explanation best fits the facts at Refuf (see map, Text-fig. 3). These are, however, the only two cases in which direct drainage from the scarp can be proved to be definitely responsible. In the smaller outcrops the tufa begins abruptly 30 or 40 m. below the edge of an entirely unindented Eocene scarp. Here either the original feeder gully was very short and shallow and has disappeared by subsequent erosion, or the water issued as springs at the junction of a marl with an impermeable shale.

On the whole it is probable that both sources were operative. In both instances the water would ultimately be derived from rain falling on the Libyan plateau, but in the case of the springs it would have more time and opportunity of collecting lime as it percolated down from the surface; in the case of the direct run off some other means of solution must be sought. This is, in all probability, to be found in the humic acid derived from the decay of the vegetation which is known to have clothed the scarp at the time. The other alternative is to suppose the carbon dioxide content of the air to have been greater, but for this there is no evidence.

In temperate regions tufa may form either from springs containing $CO_2$ under pressure or, as Dr. Macfadyen (5) has pointed out, by the action of certain kinds of mosses living in or by streams with normal lime content. Algae may act in the same sort of way, giving rise to a very porous deposit, which according to Jones (6) corresponds to the dendritic tufa of Lake Lahontan. The latter is coralline in appearance and seems to correspond closely with the coral-like masses shown in Pl. XXVIII, Fig. 1. It is, therefore, likely that algae and mosses assisted in the formation of the Kharga tufas, but it seems probable that the bulk of them owe their origin to a process still operative in Brazil which will now be described. The following is taken from J. C. Branner's (7) paper in the *Bull. Geol. Soc. America* for 1911 entitled "Aggraded Limestone Plains of the Interior of Bahia and the Climatic Changes suggested by them."

The area in question is a plateau composed of limestones alternating with quartzites and sandstones, etc. It lies to the south of the Rio São Francisco between latitudes 9° 30′ and 11° 40′ south. Across the plateau numerous tributaries run north to join the main stream, and it is in their valleys that tufa is forming at the present day. To such an extent has this taken place that the beds have been filled up till they are quite flat. The surface is covered with a short scrubby forest—characteristic of the semi-arid interior of the plateau—known as "catinga". Branner, therefore calls the tufa "catinga limestone" a name which could very well be adopted for the Kharga deposits. It is notable that this aggradation takes place only in "*those portions of the valley in which the streams are not perennial*".

Branner's description of the process is as follows :—

> "The slope of the stream bed is even and gentle, and when ever there is any sudden change of level it is marked by a natural embankment of recently formed travertine . . . They vary considerably in height, sometimes they are only half a meter high, but some of those seen are 4 meters high . . . The rock of which these natural embankments are made is not soft like the marly limestones filling most of the channels, but is rather hard on the upper face. They are all more or less overhanging and cavernous on the downstream side. Where the channel of the stream is not well defined, but spreads out to form arms and embayments, the floors of these embayments are flat and covered with the soft marly limestone. The filling usually begins at falls or cataracts and proceeds both upstream and downstream. The shallower parts fill first because of the greater exposure of the water at these places, and later the deeper pools are slowly encroached on. Any downstream slope of the stream bed that causes a rippling of the water exposes it to the air, liberates more carbon dioxide, and thus causes an increased deposition of lime on the downstream side."

Where water stands in broad shallow pools Branner describes the process as follows (p. 194):—

> "In such places the waters bring in lime from the higher grounds, to be precipitated on exposure in the warm shallow waters or on complete evaporation. These low grounds are everywhere covered with the characteristic soft deposits of lime, showing that it is precipitated from solution. The fresh deposits in these places are all soft and marly, but the old ones are as hard as any limestone ever gets to be. At many places these lime deposits, both the newer and the older ones, contain plant impressions and enclose the remains of land shells.
>
> "An impressive modification of these deposits forms where the topography is favourable. Where a broad, gentle, and rather even slope carries the lime-charged waters in shallow sheets toward a channel, the lime is precipitated more rapidly along the edge of the plain, where, on account of a change to a steeper grade, the water breaks into ripples and spray. This causes the bluff to encroach steadily on the low ground, and the process must eventually lead to the low ground being entirely filled up . . . The top of the cliff curves over like the surface of one of the travertine stream barriers. The bluff is full of caverns, produced by the irregularity of the deposit, and the roofs of the caverns are hung with stalactites. Often the travertine is deposited in masses of such shapes that they break from their own weight, and form a talus slope at the base of the bluff, and this, too, in time is covered over by later deposits and is incorporated in the great limestone sheet."

Branner (p. 195) sums up the process as a whole as

> "One of chemical aggradation, of levelling down of the older limestones by solution on the higher ground, and of levelling up by deposition from solution at somewhat lower elevations. It is to be noted, however, that the distance moved is not necessarily great; that the water is shallow and not concentrated in well defined streams; that the process is a slow creeping one, carried on over wide areas and for long periods."

The similarity between this last description and the occurrence of the plateau tufas in Kharga is striking, while the former referring to stream channels corresponds closely to the wadi type.

With regard to the climatic conditions that give rise to this process of chemical aggradation Branner may again be quoted verbatim:—

> "The rainfall over this catinga-covered country is confined to a few months in the year, and it is never great.[1] The first waters soak quickly into the ground, for the surface is very dry after months of tropical sunshine and the hot winds that blow for months of the year over this region. When, at times of rain, there is more than enough water to dampen the surface of the ground, it starts to flow, but it does not go far before it soaks into the ground. When the forest litter has once been thoroughly wet, decomposition is rapid, and the carbon-dioxide formed helps attack the lime and to move it forward in the direction of the drainage."

Branner speaks of the precipitation of lime in the pools of standing water left in the depressions of the valley floors. This undoubtedly took place also in Kharga, a minute example of it being seen in the railway cutting north of Kilo 150 at Refuf.

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[1] Joazeiro, a place on the northern margin, has 246 mm. (9·7 in.) per annum, according to the *Géographie Universelle*, xv, 1927. (E. W. G.)

But at Bulaq another means of producing the same end was discovered, which is not mentioned by Branner, and seems to be new. This is the ponding of streams due to landslips. An excellent example of it is seen in the deep longitudinal wadi referred to above (p. 391), which separates the southern plateau tufa outcrop from the main scarp (see map, Wadi 3). Pl. XXIX, Fig. 1, is a view of this wadi, looking south from the neck at 359 m., strewn with limestone and tufa boulders. On the right is the cliff of plateau tufa with the rough scree slope below, on the left, seamed with drainage channels, the Eocene marls and shales. Standing out from the light valley floor in the middle distance are two dark flat-topped tufa outcrops divided by the wadi. The floor is here broad and flat, but it will be noticed that as it is followed south it narrows to a small V-shaped channel. This is the crucial point in the wadi, for this narrowing is due to a great mass of nummulitic limestone boulders, which once completely blocked the valley. On the upstream side are found the tufas, which form the end term of a gravel and silt series (Caton-Thompson (8), fig. 2). All these deposits are dated by tools found *in situ* to the Middle Palaeolithic (Pre-Sebilian). Similar implements were found both on the tufa and around its edges.

It seems clear, then, that the landslip banked up storm waters flowing down the wadi, and caused them to deposit first the heavy gravel, then the white silts, and finally the porous cellular tufa. The tools of Palaeolithic men in the neighbourhood were washed down at the same time from the surrounding slopes. The men themselves lived around the edges of the temporary lake, and invaded the tufa surface as the water gradually evaporated and concentrated in the lowest parts. On the downstream side of the barrier, tufa is found resting directly on the Eocene boulders, and probably represents the overflow from the lake above (Pl. XXIX, Fig. 2). The levels and relations of the deposits in this valley can be seen in the section (Text-fig. 4).

It is also possible that something of the same sort has happened in the Aqaba Wadi, but in this case the barrier would have been gravels banked up on the lower slopes in earlier periods. It is a significant fact and one that requires explanation, that the Bulaq Wadi tufa outcrop both narrows and thins as it is traced westward (see map, Text-fig. 2). In shape it is triangular, with the apex at the lower westerly end, nearly 2 km. from the broad base to the east below the Eocene scarp. This is exactly the reverse of what would be expected in a deposit supplied by water draining down a valley, which naturally widens westward away from its source. This normal state is seen at Refuf.

The peculiarities at Bulaq are probably due to several causes. To begin with, it is notable that the feeder gully at the head of the Aqaba Wadi is very small to supply the great mass of tufa below and mainly to the north of it. Secondly, evidence for the existence of a pre-existing longitudinal valley below the Eocene scarp is seen in the two necks mentioned above (p. 390). There was, therefore, a tendency for the water to collect in this and possibly to drain either north or south, rather than to the west. Both these circumstances would give rise to a broad thick tufa outcrop immediately under the Libyan plateau. It is possible also that there were springs in this area to help the process, since on a line with the highest tufa north of the track a nummulitic limestone outcrop dips west at 70°. This suggests a fault or a large slip and either might have caused flow of underground water. Eventually, however, a western outlet was found and tufa was deposited in a series of rough steps probably corresponding with the outcrop of harder country rocks (see section, Text-fig. 5). The volume of water would have diminished by evaporation and absorption till finally the flow was stopped by gravel deposited on the lower slopes in periods of greater activity (see p. 404). The waters would then be ponded back and evaporated in a manner similar to those in the adjacent Pre-Sebilian wadi. In later periods this gravel barrier was cut through as the modern drainage system developed.[1]

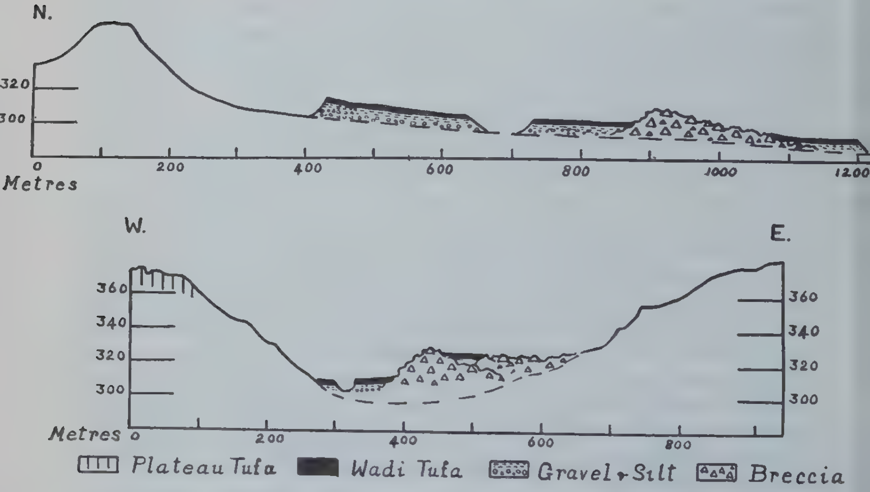

Fig. 4.—Longitudinal and Transverse Section to show the effect of ponding in Pre-Sebilian Wadi 3, by fallen and slipped brecciated masses of Eocene limestone.

*Dating of Tufa and Sequence of Events on the Kharga Scarp.*

The Pre-Sebilian tufa mentioned above was, so far as we know, the last to be formed. The dating evidence has been given, but in other parts it is not so clear as this. At Refuf it is somewhat

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[1] A full account of the physiographic development of the scarp will be shortly published in the *Geographical Journal* for 1932.

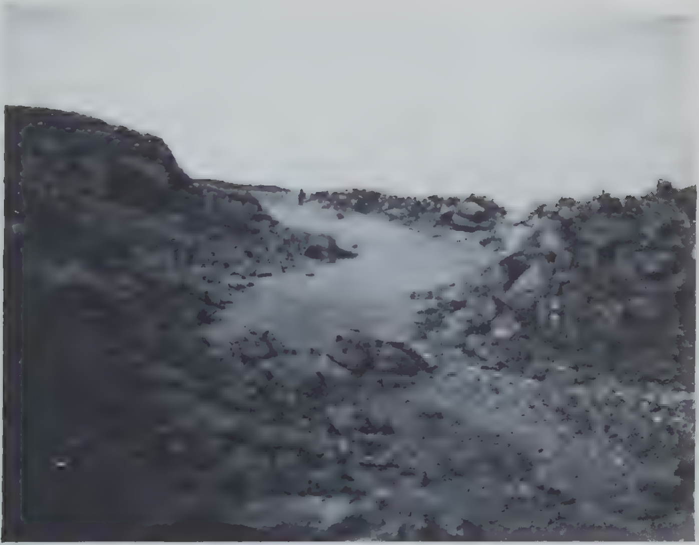

FIG. 1.—SOLUTION CHANNEL IN PLATEAU TUFA, BULAQ.

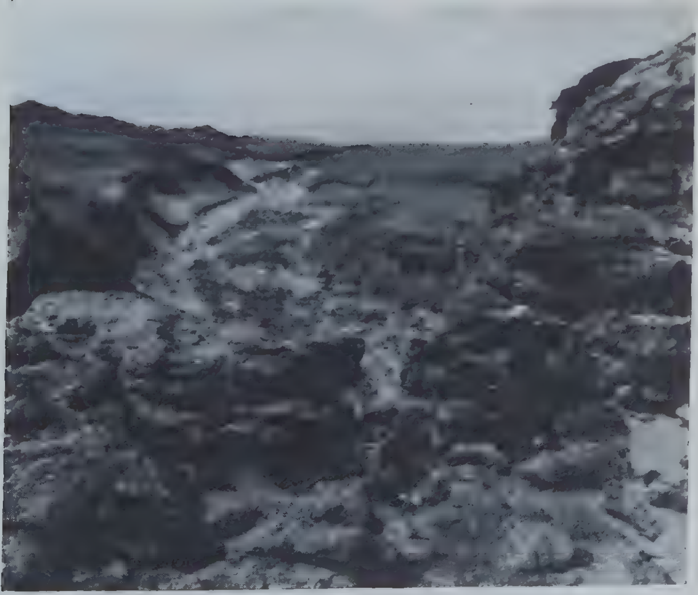

FIG. 2.—HEAD OF AQABA WADI, BULAQ, LOOKING WEST.

[*To face p.* 400.

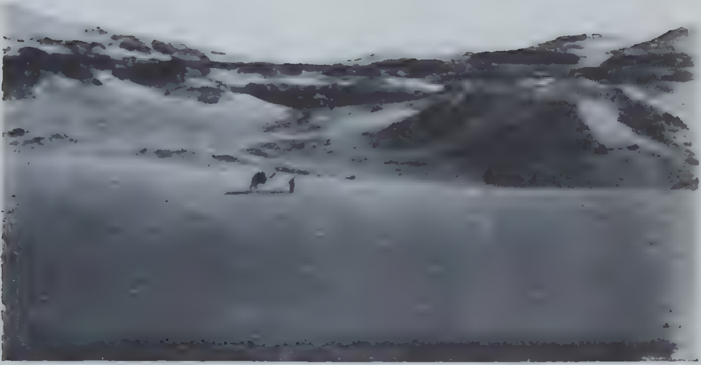

FIG. 1.—TUFA TERRACES AND GRAVELS AT REFUF PASS.

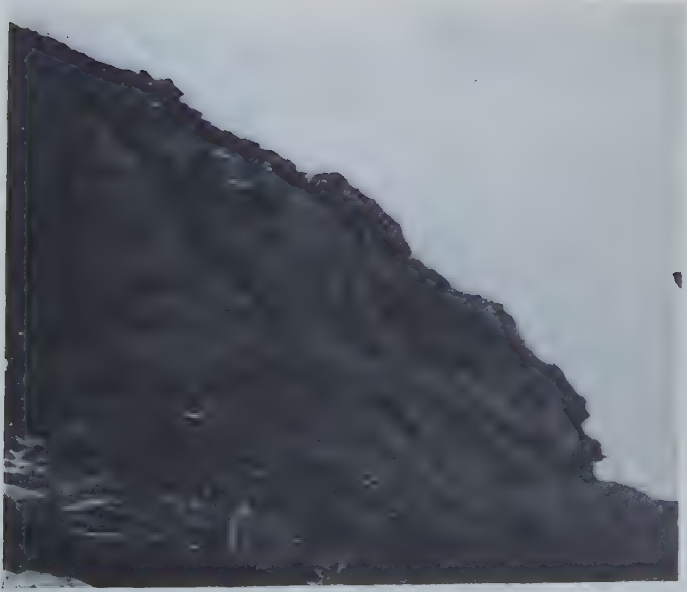

FIG. 2.—CURVED LAMINAE AT EDGE OF TOP TUFA TERRACE, REFUF.

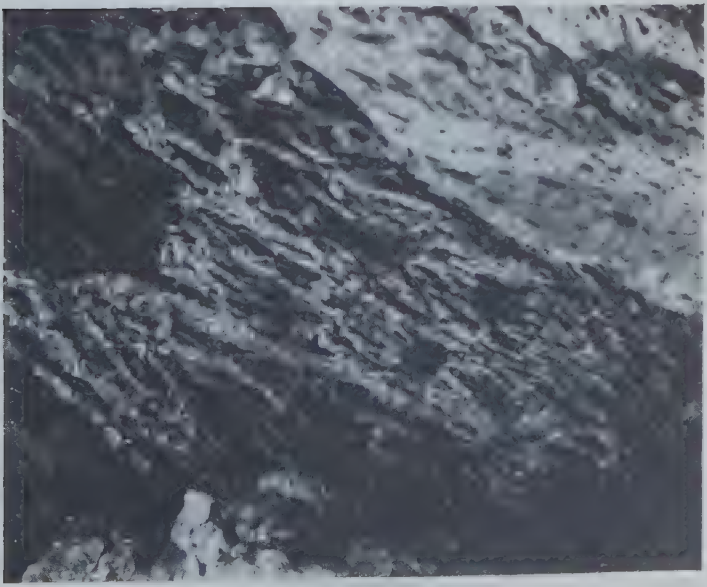

FIG. 1.—CORAL-LIKE TUFA, BULAQ.

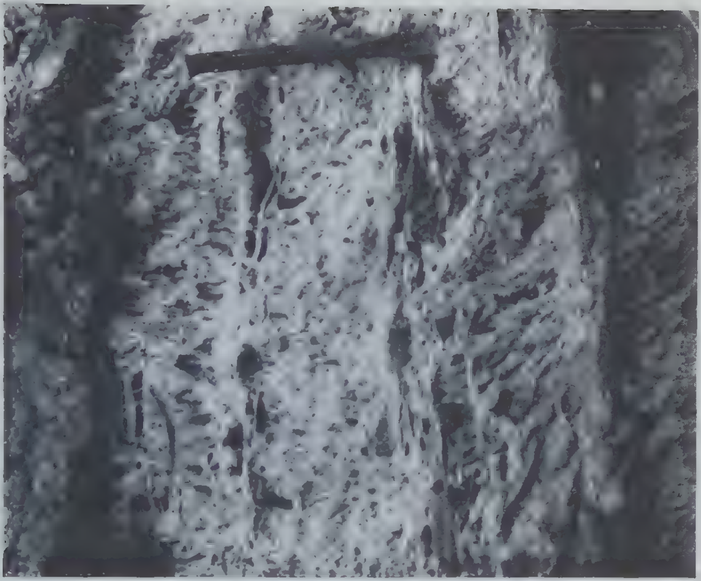

FIG. 2.—ALTERNATING LAYERS OF LEAVES AND TUFA, REFUF.

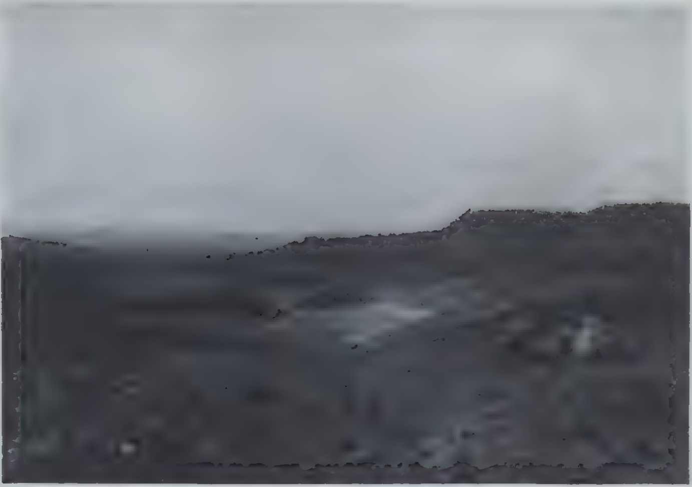

Fig. 1.—Pre-Sebilian Wadi 3, Bulaq, Looking South.

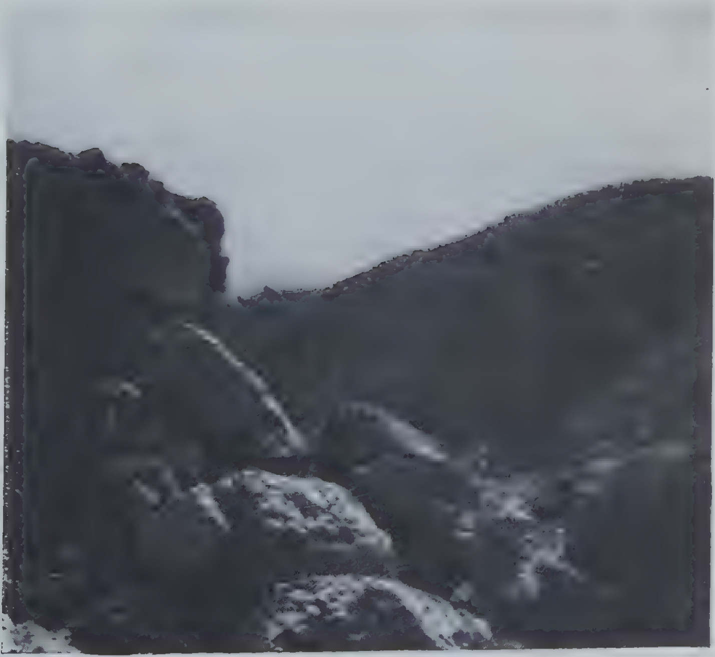

Fig. 2.—Blocking of Pre-Sebilian Wadi with Limestone Boulders.

plainer than at Bulaq, since the amount of tufa is not so great and the story is mainly one of aggradation in the early stages once the wadi was cut. At Refuf, north of the line between Kilo 150–1, the 10-metre tufa cliff mentioned above (p. 393) is underlain by a gravel containing Acheulean implements (Caton-Thompson (8), fig. 1). Above the tufa is another gravel which is well seen in the cliffs of the same wadi a kilometre further west. This gravel, which contains large tufa boulders, is overlain by white silts capped by cellular tufa—a measured section was as follows :—

| | | |
|---|---|---|
| Top, at R.L. 263 m. | 1·60–2·0 m. | Cellular tufa. |
| | ± 1·0 m. | White silts with occasional tufa layers and broken reeds. A carbonaceous band occurs half-way down. |
| | 0·40 m. | Pebbles—small limestone, chert and tufa fragments. |
| | 0·50 m. | White sandy silt. |
| | 0·10 m. | Coarser intermittent pebble layer. |
| | 2·0 m. | Sandy silt with gravels coming in to the west. |
| | 7·0 m. | Alternating gravels and coarse silty sands. Large limestone and tufa boulders especially towards the base. |

Scree slope to wadi floor at 233 m. above sea level.

Implements of Acheulean and Levalloisean type were found throughout this series, except in the tufa itself. In the sections (Text-fig. 5) it will be noticed that the tufa surface has a rapid but regular westerly fall. The Pre-Sebilian tufa has not been found at Refuf.

At Bulaq the tufa stages before the Pre-Sebilian are harder to disentangle. At the head of the Aqaba Wadi and for a considerable distance westward the base of the tufa is not exposed. When it does appear it is underlain by a coarse thick breccia which has a wide development in the oasis. In the wadi immediately north of the track the tufa rests on gravels and silts. From evidence considered below, the " breccia " tufas are generally regarded as older than those on gravels. At Bulaq the gravels in this northern wadi yielded Acheulean and Levalloisean tools, the breccias are apparently always barren. An Acheulean hand axe was found on the tufa surface with tufa deposited on it. This does not prove the deposit Acheulean, but in view of proved Acheulean tufa at Refuf and of the fact that the " breccia " tufas are generally at a higher level and more eroded than the " gravel " tufas, the former are taken to be older than the latter (section of Sighawal Pass, Text-fig. 4).

The wadi tufas are separated from the plateau type by a long period in which two important events took place. The first was a great period of erosion in which transverse valleys were deepened, longitudinal ones developed, and gravels deposited on the lower slopes. Apart from the physiographic evidence, the deposits underlying the tufa in the Aqaba Wadi contain huge boulders of brown sandstone with bands of pebbles of limestone and massive tufa. There is no sandstone in the country rock above these occurrences and, therefore, the only source of the deposit is the material of a consolidated wadi floor. Sand, exactly similar in colour and texture, was found in the modern valleys. Streams, then, were eroding the plateau tufa before the formation of the later types; but what caused the consolidation and breaking up of these alluvial deposits? The answer to this question seems to the author to be found in the character of the surrounding material. Both in the Aqaba Wadi and in those further north there is an enormous development of breccia beneath the tufa. This breccia is made up of angular fragments of limestone, with, in the Aqaba Wadi, the addition of massive tufa and conglomerate sandstone blocks. The size varies greatly, but nowhere is there any attempt at sorting, or other signs of water action.

A measured section on the right bank of the Aqaba Wadi about 2 km. from the top is as follows :—

| | | |
|---|---|---|
| Top. | ± 3·0 m. | Cellular tufa with intercalated silts. |
| | 0·25 m. | White silt. |
| | ± 20 m. | Breccia with large tufa and limestone blocks. |

One block of massive banded tufa on the wadi floor measured 11 × 7 × 3·5 m. In the *Geographical Journal* other illustrations of this great breccia episode will be found.

It is hard to find any cause for this other than a lengthy period of great aridity, when extreme diurnal temperature changes produced rapid mechanical weathering. The absence of tools precludes exact dating, but the great thickness, together with the amount of erosion the breccia has undergone puts it back to an early period. Since the oldest wadi tufa so far discovered is Acheulean, and wadi tufa always rests *on* it, it must precede the Lower Palaeolithic, but by how much we cannot say.

It is of interest in this connection to note that breccia formation on a large scale is found in other parts of Egypt. Blanckenhorn (9) states that the movements in the north of Egypt in the Lower Pliocene resulted in a great increase of weathering giving rise to the formation of breccia.

Dr. K. S. Sandford (op. cit.) describes calcite and "breccia" (the inverted commas are the present author's) 30 feet thick at the foot of a black travertine cliff in Wadi Qasab on the right bank of the Nile. The material is apparently mostly well rounded and can therefore not be a breccia in the usual sense of the term. On the left bank, however, at the south corner of "Abydos Bay" the true red breccia of Pliocene age is found capping the travertine (p. 514). The latter rests directly on the Eocene and the succession would, therefore, appear to be similar to that in Kharga, the Nile Valley deposit being equivalent, as suggested above, to the plateau tufa, the rounded boulders to the period of erosion, and the sandstone in the Aqaba Wadi, Bulaq and the red breccia to the great breccia deposit filling the Kharga valleys. The reality of the breccia episode is still further substantiated by Dr. Sandford's observation that breccia formation on any large scale is confined to the Pliocene (p. 488); the difference in the two regions being that in the Nile Valley the screes fell into the placid waters of a gulf, while in Kharga they slid slowly downhill to fill the empty valleys formed in the preceding period of erosion. In the discussion on Dr. Sandford's paper the red breccia was compared to the Permo-Triassic deposits of Cumberland, long acknowledged to be of desert origin. Further, Mr. W. B. Wright regarded it as similar to the deposits in N.W. Peru described by Bosworth, his conclusion being that " it indicates freedom from general sedimentation, probably due to desert conditions on land ".

After this dry period there was a return to wetter conditions, and tufa was laid down on the breccia in the Aqaba Wadi and elsewhere. Erosion, probably due to increased rainfall, followed, and in the valleys, cut through breccia and tufa, a gravel-silt-tufa series was laid down. These are the Acheuleo-Levalloisean deposits referred to at Refuf, and from their extensive development this stage would seem to have been one of the most important in the history of the oasis. The relation of the " breccia " tufa to this later Palaeolithic type is seen in the Sighawal Section (Text-fig. 5). It led up to another period of erosion when wadis were cut through the tufas, and gravels and pre-existing wadis were deepened. The evidence for this is seen in the erosion of the tufa platform at Refuf (see map, Text-fig. 3), and at Bulaq in the deep, broad, longitudinal wadi already referred to, which in the next stage was partially filled by the Pre-Sebilian tufa series. From then onwards there was a steady decrease in precipitation and therefore of run off. The vegetation died, the accumulated humus was dried up and eroded by the wind, and tufa deposition ceased. The modern drainage system gradually assumed its present form, the diminution in supply being reflected in the continued contraction of the wadi courses (see *Geog. Journ.*).

The sequence of development and climatic conditions of the Kharga scarp are discussed in the *Geographical Journal*. For completeness they may be summarized as follows :—

### *Summary of Sequence of Events on Kharga Scarp.*

#### PLIOCENE OR PLIO-PLEISTOCENE.

1. Deposition of plateau tufa : some rain.
2. Erosion ; development of longitudinal and transverse valleys : more rain.
3. Breccia formation on large scale for long period : little or no rain.

### PLEISTOCENE.

*Acheulean* (Lower Palaeolithic) :—

4. Deposition of wadi tufa on breccia : some rain.

*Acheuleo-Levalloisean* (transitional) :—

5. Erosion of 4 by wadis : more rain.
6. Deposition of wadi tufa, silts, and gravels in wadis formed in 5 : less rain.
7. Erosion of deposits in 6 and deepening of valleys : more rain.

*Pre-Sebilian* (late Middle Palaeolithic) :—

8. Deposition of tufa on gravels and silts in modern drainage channels, but less than in 6 : less rain.

*Aterian* (Early Upper Palaeolithic) :—

9. Erosion on much smaller scale than before; formation of terraces in modern drainage channels : less rain.

*Capso-Tardenoisean* (late Upper Palaeolithic or Mesolithic) :—

10. Erosion on still smaller scale; formation of second terrace : less rain.

### *Summary of Tufas.*

The Kharga tufas fall into two types differing in physical characters, age, and position.

(1) *Plateau Tufa.*—A high-level hard, massive rock, practically devoid of life, resting directly on the Eocene. It was not definitely dated, but for physiographic reasons is considered to be the oldest deposit, possibly equivalent to the Nile Valley Pliocene tufas.

(2) *Wadi Tufa.*—A softer, cellular type with a much wider distribution than the plateau tufa. It never rests on Eocene or Cretaceous, but on either a coarse breccia or a gravel-silt series. It contains, at least, seven kinds of plants, eight land, and eight freshwater gasteropods. The land shells are now living in England, Central Africa, and Egypt, the aquatic mollusca are all modern Egyptian forms.

From a comparison with present conditions of tufa formation in Brazil, the process is regarded as mainly one of chemical aggradation. It is suggested that the term " catinga type " be adopted after the name given to it in Brazil. The physical conditions necessary for this type are :—

(*a*) Calcareous country rock.
(*b*) Intermittent streams with shallow water.
(*c*) Temperature sufficiently high to cause precipitation in the warmed waters.
(*d*) Presence of vegetation, whose rapid decomposition provides the acid necessary for the solution of the limestone.

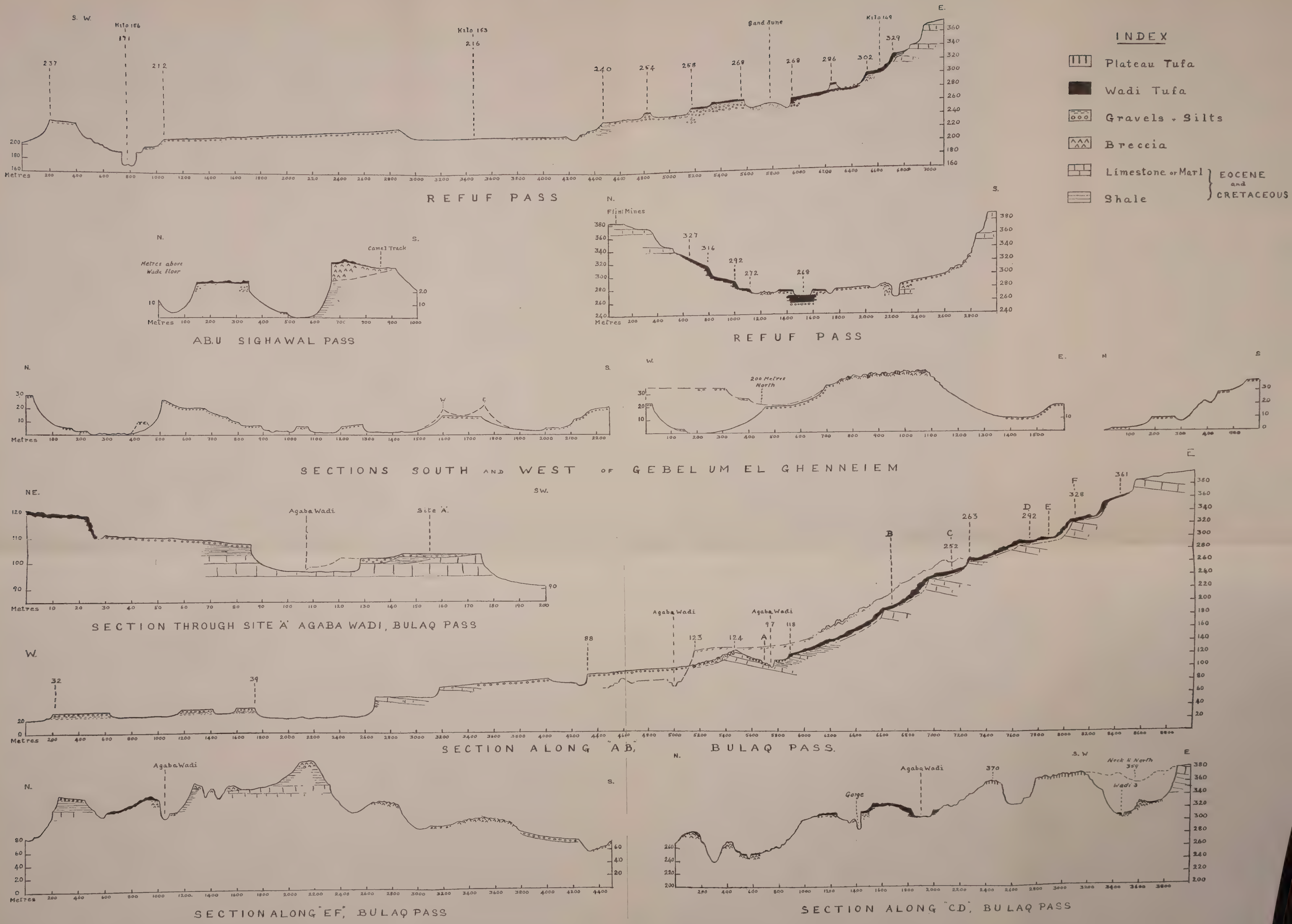

Fig. 5.—Sections of tufa and gravels between Bulaq and Refuf Passes.

To face p. 405.]

The rainfall is regarded as having been small in amount and seasonal in type during the periods of tufa formation, increasing in the intervening periods of erosion, but never reaching the amount typical of a Mediterranean climate.

The date of the wadi tufas is determined partly by studying the physiographic development of the scarp, partly by the associated tools. Three different periods of tufa formations were established :—

(i) Lower Palaeolithic : Acheulean.
(ii) Transitional : Acheuleo-Levalloisean.
(iii) Late Middle Palaeolithic : Pre-Sebilian.

The second episode was the longest and most important.

## B. Pleistocene Hydrography of the Floor of the Depression.

To what extent were the climatic conditions described above reflected on the floor of the oasis ; was there an appreciable increase in rainfall there also ; and did the run-off from the scarp accumulate as lakes ? These questions will be answered in the negative in the *Geographical Journal*, and the reader is referred to this paper for the argument. Evidence is there given that leads the author to discard Beadnell's suggestion of a lake or lakes on the oasis floor, and an alternative explanation is offered for the peculiar wind-eroded deposits which gave rise to the lacustrine hypothesis.

The purpose of the present article is to describe what appears to be the main source of Pleistocene man's water supply. This is to be found in a series of sandy mounds, not very conspicuous features of the desert surface, but remarkable for their crater-like shape and the quantity of implements that lie on or about them (Pl. XXX, Fig. 1). Indeed, apart from the stray tools that can usually be found anywhere over the desert, the artifacts of early man are largely concentrated in the neighbourhood of these mounds. A section across one of them (Text-fig. 8) revealed a series of sands, clays, and loams, regularly bedded in one part, but intensely disturbed along a vertical line in another ; clays on the edge of the deposits either dipped steeply inwards or showed strongly slickensided surfaces with a high hade. This type of structure occurred in other mounds, and the only explanation that seemed to fit all the facts was that it marked the site of springs, active on the floor of the depression in times past. Beadnell (op. cit.) suggested that such springs might have occurred as the water-charged upper sandstone was gradually uncovered by the erosion of the overlying clays, but he did not find any early springs, and this would seem to be the first record of them in Egypt.

### *Distribution.*

The springs occur in groups located along definite lines. The biggest group so far discovered lies some 7 or 8 km. east of Kharga village, and stretches from just west of Ain Kharran north-

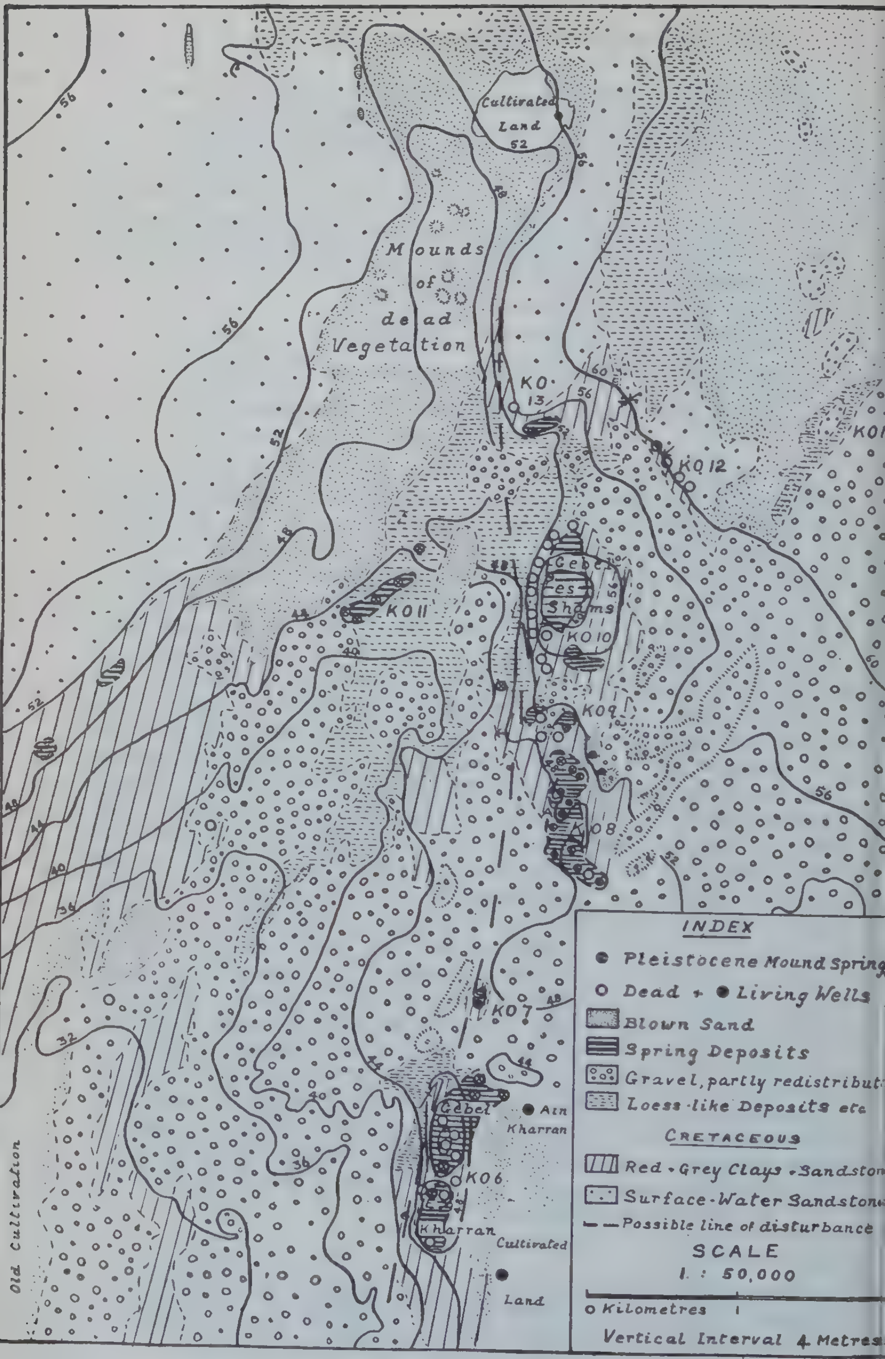

FIG. 6.—Map of Mound Spring Area, 7 kilometres east of Kharga.

ward for about 5 km. The map (Text-fig. 6) shows that the distribution is not continuous along this line, but that there is a northern and a southern group separated by barren gravel-covered ground. A third subsidiary group lies at an oblique angle to the northern one in a south-westerly direction. The surrounding floor is everywhere Nubian red clay, but it is here considerably below the normal lower limit of R.L. 62 m. West of the spring line, thin outcrops of hard ferrugineous sandstone occur in the clays, while to the north and north-west the underlying Surface Water Sandstones give rise to higher ground. To the east an extensive low gravel plateau stretches away towards the scarp. The springs are not in the lowest part of this area, but occur mainly along the eastern slopes of a shallow, broad valley opening to the south-west.

### *Age of Springs.*

The springs can only be dated exactly by the tools found in them, and since only five have been excavated the following sequence may be subject to revision, but a certain amount of additional information can be obtained by examining the surface implements near the springs. The first people to use the spring water were, apparently, the Acheuleans. No early Lower Palaeolithic artifacts have been found anywhere in the oasis or on the scarp, whether because the springs had not yet broken out, or were not then discovered, is not known. The Acheulean spring lay near the northern end of the group between R.L. 59–61 m. (K01O on map, Text-fig. 6). The vent was not located, but the deposits were characteristically disturbed and many of the tools were remarkable for their highly glazed surfaces. Towards the southern end of the northern group one mound (K08A, Text-fig. 9), was found to contain a Middle Palaeolithic gravel sharply truncated by the vent. In the southern group a large Aterian (Early Upper Palaeolithic) floor occurred near the top of a series of sands, clays, and loams. This floor also ended abruptly against disturbed deposits, which must indicate the subsequent eruption of the spring, and this activity is the last of which we have record. In Neolithic times the springs had ceased to flow, and water was obtained from the mounds by digging.

### *Description of Springs.*

A description of two springs will serve to show their characteristics and the main types of variation.

(1) K06E (Plate XXXI, Fig I, Text-figs. 7 and 8).

The first is in the southern group near Ain Kharran, along with several others and numerous old wells. It is situated on a low north–south ridge rising some 10 m. above the surrounding plain; the western slope is steep and though Cretaceous clays are visible in small areas, most of it is covered by spring and well deposits.

K06E is in about the middle of the ridge between two old wells. It is an oval crater-like mound. The long axis, measuring ± 20 m. between the crater rims, lies north-west–south-east; the short is 15 m. The northern rim is broken by wind erosion, which has also hollowed out the interior (see plan, Text-fig. 7). The highest part of the rim at R.L. 57 m. rises 5–6 m. above the surrounding ground. The surface is mainly hard green or reddish sandrock, which extends down under the rim to an unknown depth. It seems to form a lining to the vent, since in the south-east the margin slopes steeply inwards and is overlain by clays with the same dip (see section, Text-fig. 8). Towards the centre of the crater the sandrock is 1–1½ m. thick, and tends to become less compact. Nearly everywhere it contains many iron-stained root-like markings, these being particularly abundant under the rims. Towards the base is a thin layer (±1 cm.) of aluminium sulphate,[1] more continuous in the north and west than in the south and east.

The constituents of the sandrock are all more or less iron-stained quartz grains averaging 0·75 mm. in size, with larger ones ranging from 1 to 1·5 mm. All these are well rounded and show a dull "frosted" surface (Pl. XXX, Fig. 2), the smaller particles are clearer and more angular. In some places pockets or pipes of the coarser material penetrate the underlying beds. The rock closely resembles consolidated dune sand, the striking difference being in the absence of lime. This is a general feature of all the Kharga spring deposits, and the cause of it will be discussed later.

The following description of the beds underlying the sandrock refers to the north and west sides only, the succession and structure in the east and south is different and is treated separately (p. 409).

Under the sandrock in the centre of the area is pure white sand, much finer than the bed above, and containing pockets of almost flour-like consistency. It is saccharoidal in texture, and consists of transparent quartz grains less than 0·5 mm. in size. A few are well rounded, but the majority are subangular to angular. On the surface of this sand an extensive chipping site was found, consisting of many tools and thousands of waste flakes (Pl. XXXI, Fig. 1). The tools are Aterian and date this stage of the spring to the beginning of the Upper Palaeolithic. To the north-west and west the floor ran up on to a hard green clay, which here directly underlies the sandrock (see section, Text-fig. 8). Traced towards the centre this clay passes with a steep slickensided surface under the white sand. Much fibrous gypsum occurs in this deposit and two tools were found in it. The thickness of these two beds varies, but the white sand averages 1 m., the clay ½ m. Underlying the clay is a loam, ¾ m. thick in the centre, thinning out to nothing on the west and north-west, and ending off on the south-west against an inwardly dipping slide.

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[1] For the chemical analyses of all the solids the author is indebted to Dr. D. Jordan Lloyd.

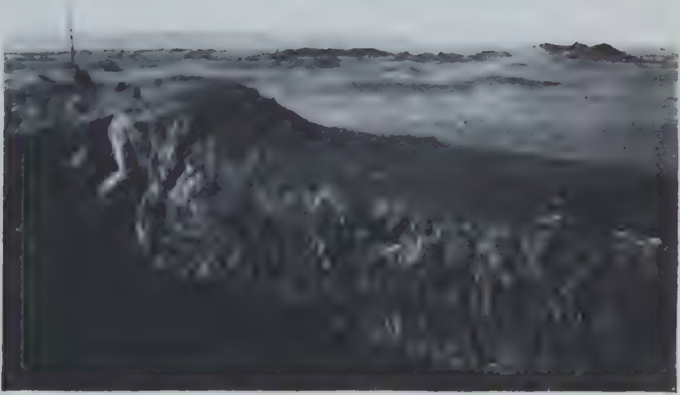


FIG. 1.—MOUND SPRINGS AT K08. SPRING A FOREGROUND, C DISTANCE.

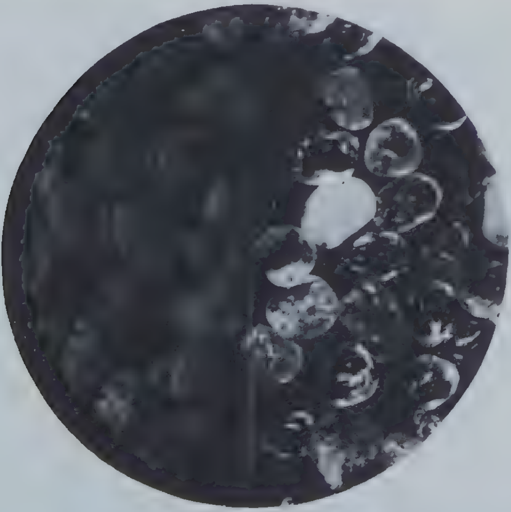


FIG. 2.—FROSTED SAND GRAINS (LEFT) AND POLISHED GRAINS (RIGHT) FROM MOUND SPRING K06E.

[*To face p.* 408.

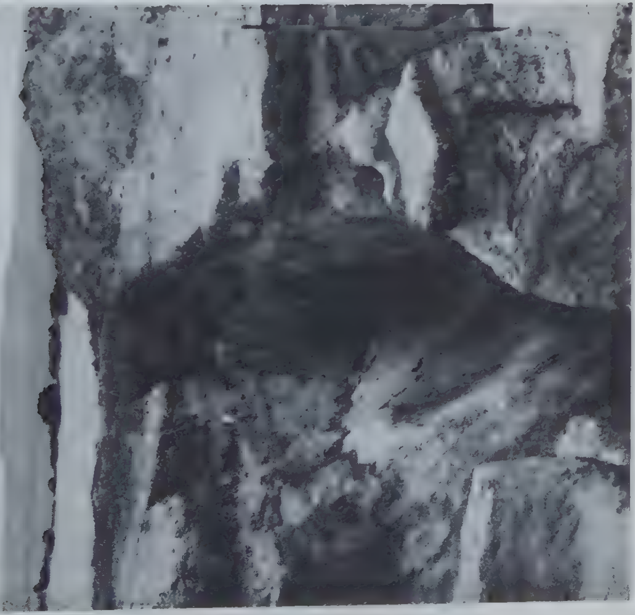


FIG. 1.—CLAY SLIDE (LEFT) AND ATERIAN FLOOR (RIGHT FOREGROUND) IN SPRING K06E.

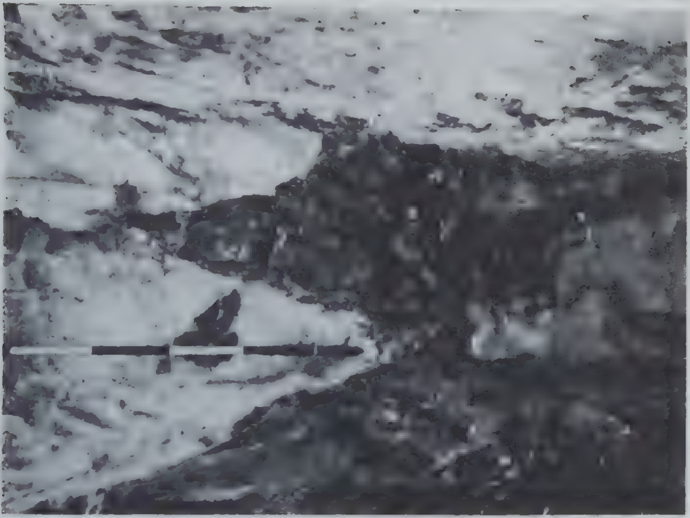


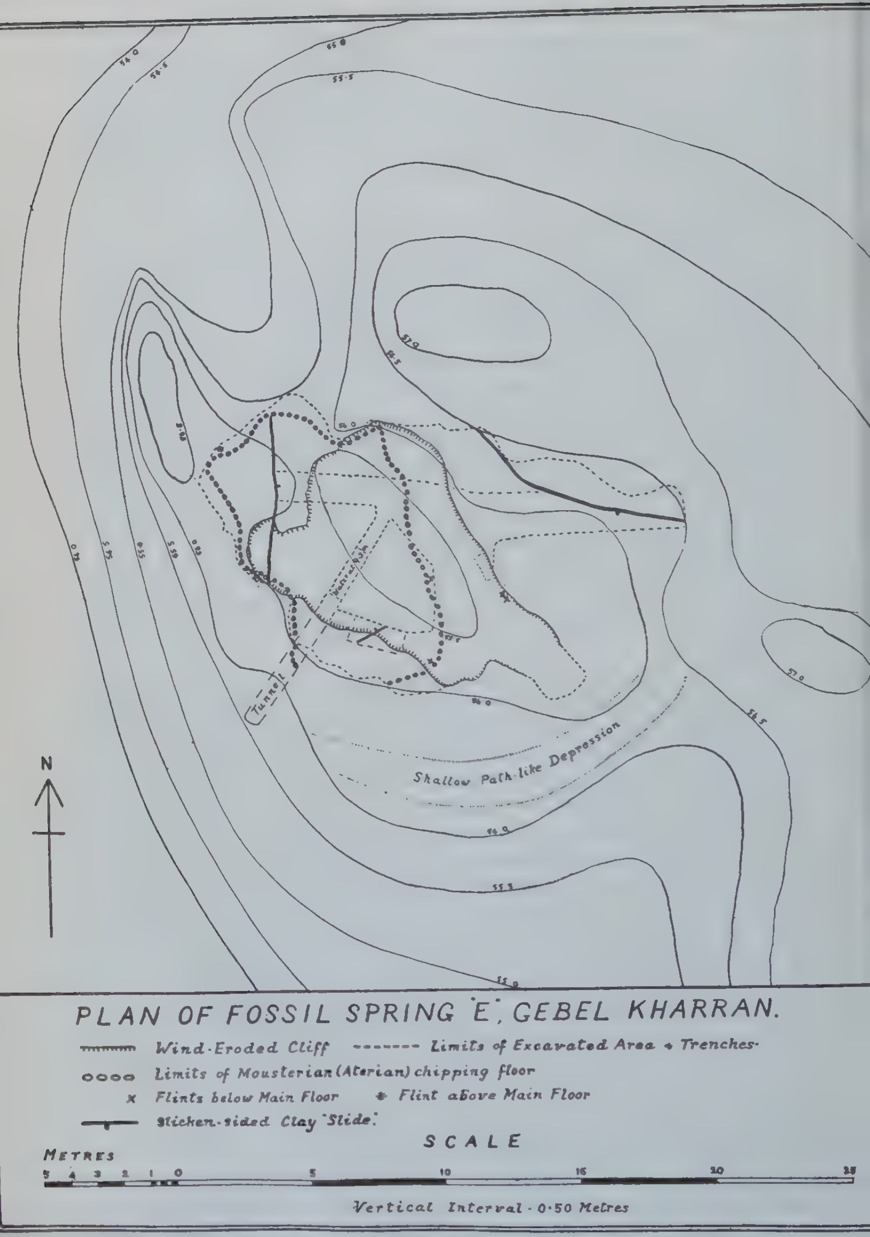
FIG. 2.—BROKEN AND DISTURBED RED CLAY IN WHITE SAND OF VENT, K08A.

The outcrop is plano-convex in shape, the flat surface being uppermost; it rests on mixed clay and sandrock. The loam which is intermixed with a considerable amount of fine grey clay and sand, contains numerous carbonized reed stems, but no other signs of life except a few small bean-like objects which have been kindly identified by Mrs. Clement Reid as the seeds of the wild date, *Phoenix sylvestris* Rosch, recorded at Kew from Mount Tiila in the Punjab Salt Range and from Ruwenzori.

A feature specially characteristic of the loams, but found also in the other deposits, is the occurrence of a sulphur-yellow substance, sometimes in irregular lumps, sometimes as root-like concretions. This substance is harder than the surrounding material and is etched out by wind erosion on an exposed surface. It consists largely of an oxide of iron with a certain amount of some sulphur-containing acid, the pH value of the aqueous extract being 3·07. A large part is soluble in hydrochloric acid, the soluble portion containing iron and aluminium. The insoluble material resembles silica, a conclusion supported by the heat evolved when the yellow earth is treated with hydrofluoric acid. On heating dry, water vapour and sulphur dioxide are given off. This substance was found in all the other mounds examined, but was more abundant in some than in others.

A fairly regular alternation of these sands, loams, and clays was found in a pit dug to 9·3 m. in the centre of the crater (R.L. 46 m.). At this depth work was stopped by the infiltration of water.

It will be noticed, (Text-fig. 8) that the two slickensided surfaces in this area are of different ages, that in the south being the older and larger. As the floor was traced eastward it was found to stop abruptly along a fairly definite north and south line. East of this not a flint was found at floor level (1–1½ m. below the surface) though two occurred below a loam 3¼ m. down. A section of this area is seen in Text-fig. 8. In the north the white sand of the floor is overlain partly by sandrock, partly by rubble from the adjoining well. After a few metres this sand and the underlying loam end abruptly against a vertical pipe of coarse material leading down from the sandrock above. The aluminium sulphate layer is here broken off and bent downwards. From this point southward the bulk of the material is a disturbed fine yellowish sand, the colour being due to intermixed yellow earth. It contains numerous stringers and pockets of comminuted clays and loams. The deposit hardens to the south where it overlies the steeply sloping clay mentioned above as lining the vent. As this clay is followed downward it thickens and passes into a loam on the same horizon as the truncated deposit to the north. This loam is much disturbed and contains numerous lenticles of white sand; on its northern side it stops short against the yellow sand which here separates the two loams in a pipe 1¼ m. broad. In this pipe are numerous vertical stringers of clay and coarse iron-stained sands. The whole deposit becomes more


54.0
54.5
55.0
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57.0
56.5
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55.5
55.0
Tunnel
Shallow Path-like Depression
N
PLAN OF FOSSIL SPRING "E", GEBEL KHARRAN.
Wind-Eroded Cliff
Limits of Excavated Area + Trenches
Limits of Mousterian (Aterian) chipping floor
x Flints below Main Floor
+ Flint above Main Floor
Slicken-sided Clay "Slide."
SCALE
METRES
5 4 3 2 1 0 5 10 15 20 25
Vertical Interval · 0·50 Metres

Fig. 7.—Plan of a Pleistocene Mound Spring K06E, showing area of Upper Palaeolithic floor.

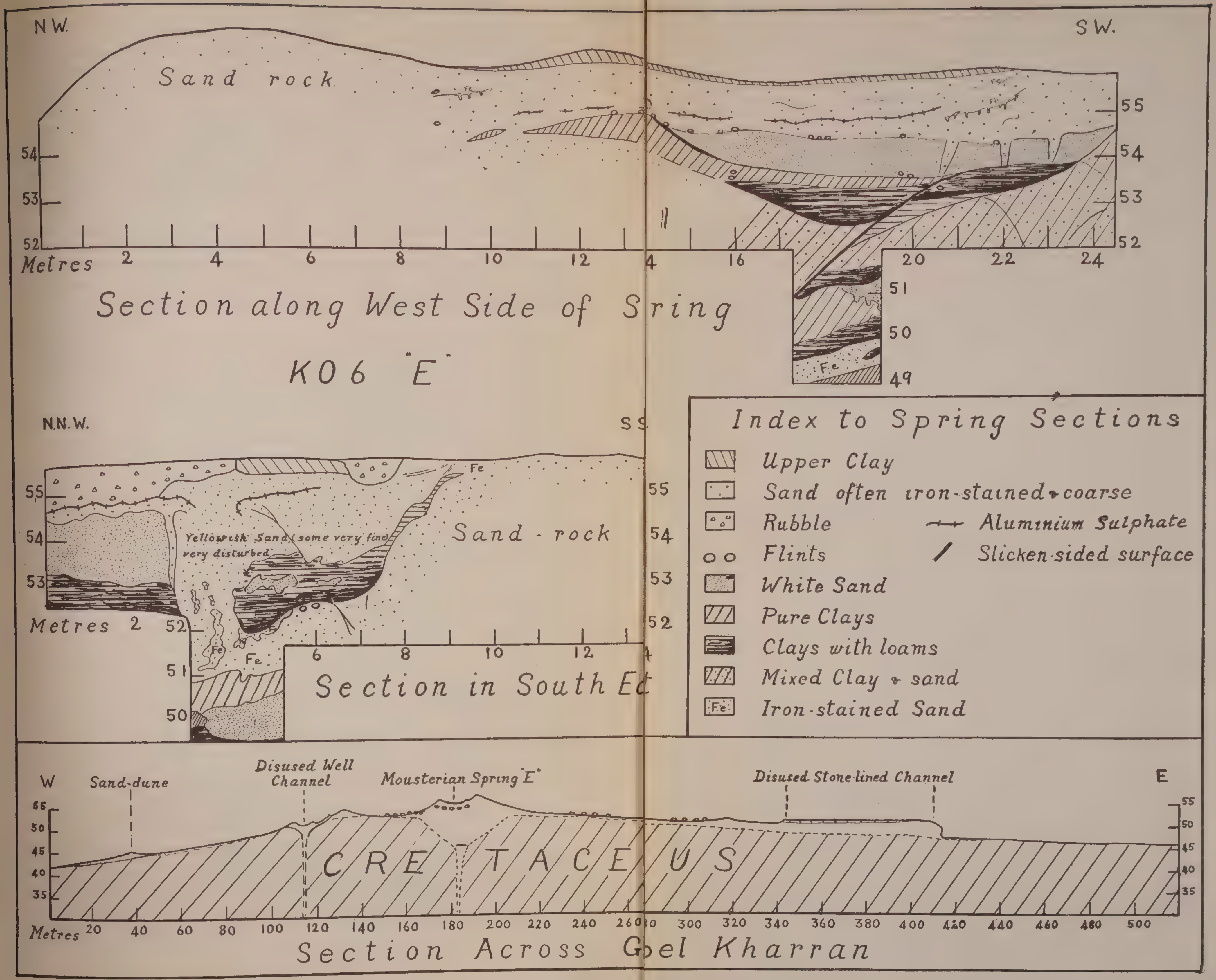

FIG. 8.—Sections of Pleistocene M Spring, east of Kharga.

[*To face p.* 410.

iron-stained as it passes under the loam. The pipe in this part does not continue down indefinitely, but ends with an irregular junction against a grey clay. Between this and an underlying loam and clay is a lenticle of fine sand, remarkable for the high polish of the rounded grains. Under the microscope rose-coloured, yellow, translucent, and clear quartz shine like jewels (Pl. XXX, Fig. 2). Dune sand, examined for comparison, did not show this high polish, which is therefore attributed to agitation in water.

A section in the north-east of the crater revealed even greater disturbance of the deposits, which here abutted against a big slickensided clay surface (Pl. XXXI, Fig. 1). From the east end of the trench this bore 104° for 6¼ m., after which it was traced north-westward for another 2½ m. The average hade was 32°, with slickensiding parallel to it. Towards the middle of the slide the clay was 20 cm. thick, but downwards and westwards it became a mere skin over sand.

Owing to lack of time it was impossible to trace the limits of this interesting structure. It is, however, certain that it is the biggest and latest of the three slides. Like the others the slope is inward, and the greatest area of disturbance lies against it. These facts, in conjunction with the abrupt termination of the flint floor, strongly suggest that we are here dealing with the actual vent along which the last eruption of the spring took place.

The actual outlines of the original vent were not traced, but Cretaceous clay at 52 m. just north of the mound proves its existence.

*Nature of Water.*—The water which filtered into the spring deposits at R.L. 46 m. may have been derived from the adjoining wells, but its composition is of interest, since some of the well water, if not all, must have been derived from the same source as the spring.

The following analysis is published by the kindness of Mr. O. H. Little.

| | *Parts per million.* |
|---|---|
| Total solid in solution | 960 |
| Permanent hardness as $CaCO_3$ | *Nil.* |
| Alkalinity after-boiling, as $CaCO_3$ | 132 |
| Chlorine | 252 |
| Sodium chloride | 415 |
| Nitrates and nitrites | — |
| Alkalinity (French degrees) | 23·8 |
| Sulphates as $SO_3$ | 79 |

This water is regarded as potable, but its considerable acidity was shown by the blackening and rotting of the cotton bag which contained the damp sand when it reached England. On analysis this sand gave a very acid aqueous extract (pH value 2·5), the acidity being due largely to ferric sulphate together with some ferrous and aluminium sulphate. Direct evidence of the acidity of the spring waters is found in the deposits themselves, namely :—

(1) The presence of aluminium sulphate.
(2) The sulphur-containing acid in the yellow earth.

The absence of shells, bones, and lime from all the spring deposits would then be accounted for, though from the close association of early man with this spring it must be assumed that the water was drinkable.

Finally, the fairly regular alternation of sands, clays, and loams, would seem to indicate periods of activity separated by times of quiescence, when the vent was occupied by a more or less stagnant, reed-fringed pool. The closing phases of this activity are dated by the tools to the Upper Palaeolithic, but the proved 7 m. of deposit beneath the floor shows that its history began at an earlier but unknown date.

### (2) K08A (Pl. XXX, Fig. 1 ; Text-figs. 9–10).

The spring now to be described lies near the southern end of the northern group in low-lying ground between R.L. 48–9 m. There are eighteen springs in a small area 900 by 400 m. ; their distribution and levels can be seen in Text-fig. 9. The country rock is red Cretaceous clay with overlying gravel to the east at R.L. 54 m. This gravel, ±1 m. thick, is a well stratified deposit of medium sized rounded limestone pebbles and occasional chert, interbedded with sand. The weathered red clay surface below and the gravel above both contain Middle Palaeolithic implements.

Most of the springs in this group are characterized by very perfect conical forms, especially K08A and its immediate neighbours (Pl. XXX, Fig. 1). The mounds rise 2–3 m. above the floor, the absolute levels ranging from 55 m. in the north to 48 m. in the south-west.

K08A itself is an almost circular mound with a diameter of 25 m. at the base and 10 m. across the top between the crater rims ; inside the crater the lowest point is R.L. 49 m., the highest on the rim at R.L. 50 m. This rim, like the others, is made of sandrock covered in many places with a network of concretionary sand in the form of intertwining narrow rods and branches, sometimes 20 cm. or so thick. An east–west section across the centre of the mound is seen in Text-fig. 10. In this case the edge of the vent is well defined ; it is a vertical junction between soft sand and the truncated edges of a hard gravel and sandrock series. This eastern boundary lies 1½ m. west of the eastern crater rim, the western limit was not exposed, but as the junction was traced southward it was found to curve gradually inwards. A pit carried down to R.L. 40·2 m. (i.e. 9 m.) in the vent did not reach the country rock.

It passed through white and pink fine-grained sands with vertical stringers and pockets of red clay, or comminuted clay mixed with sand (Pl. XXXI, Fig. 2). Implements were found at the edge of the pipe and scattered through it, particularly in and about the clay inclusions. These implements are derived from the gravels on the east of the vent, and are Middle Palaeolithic in type. They rest on a weathered red clay surface with incorporated gravel in the same manner as the gravel of the plateau. They differ from the latter, however, in the absence of stratification and sorting, which

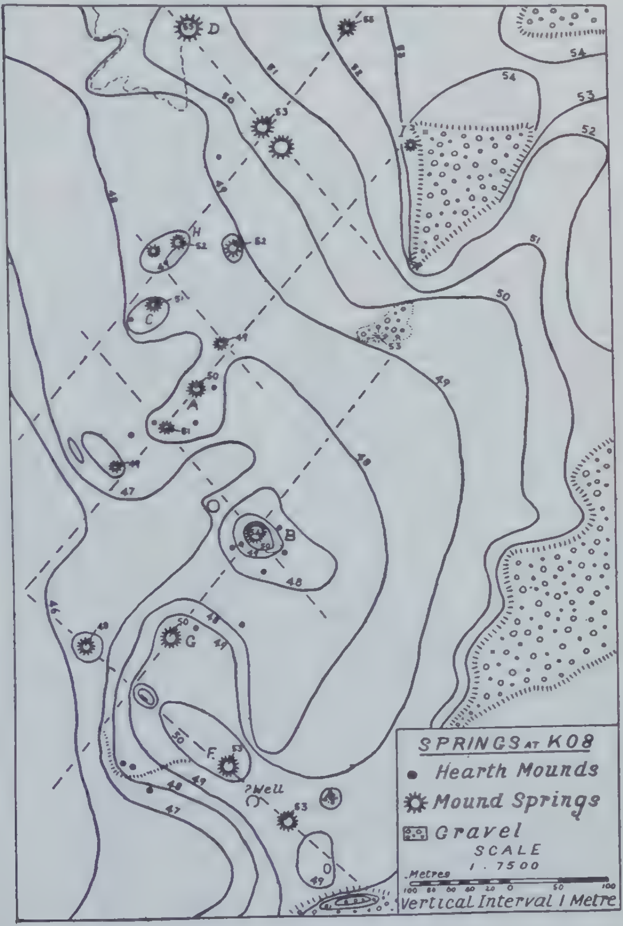

FIG. 9.—Plan of Pleistocene Mound Springs, east of Kharga, to show linear arrangement (indicated by broken lines).

suggests that they are redistributed. The constituents are limestone and some chert, and vary in size from quite big boulders 0·3 m. in diameter to small pebbles; some are well rounded, others subangular. Noticeable features are the thickness of the white chalky weathered zone around the cherts, and the occasional abnormal lightness and porosity of the limestone. At the time of writing none of this year's material has yet returned from Egypt and therefore no chemical or microscopical examination has been possible. The implements, worn and unworn, are scattered indiscriminately through this gravel. At the vent there are two narrow bands separated by a varying thickness of hard clay and sandrock. The base of the series is at R.L. 43·3 m., the top of the clays and sandrock above the upper gravel at R.L. 47 m.

Passing eastward (i.e. outward) from the vent this whole series is cut off after about 5 m. by a clay slide hading towards the vent at 30°. The red clay is here at 44·6 m.; on the up-throw side the gravel unites into a band 0·3 m. thick, but the overlying clay and sandrock series (4 m. thick on the down-throw side) is reduced to a layer of 0·2 m. that rapidly dies out eastward. In about 4 m. the gravel tails out against a red clay slope formed by erosion, not slip, and on the more or less horizontal surface above at R.L. 46·8 m. there are only a few scattered pebbles.

The sandrock series is on the whole coarser than that at K06E; it contains frequent lenticles of large rounded grains interspersed with very worn nummulites. It closely resembles the surface material of the present day, derived partly from blown sand, partly from the wash of occasional rains. The fine sand of the vent, on the other hand, can only be compared with the Surface Water Sandstone and the white sand of the flint floor at K06E. Rare fragmentary animal bones were the only sign of life in these deposits.

Above the Palaeolithic gravel-sandrock series is 2–3 m. of yellow or reddish sand with thin lenticles of red and grey clay. Neolithic tools occurred throughout and, towards the top, were found hearths lined with stones. The sand is obviously wind blown, but the presence of clay bands indicates that it was accumulated on a surface subject to intermittent flooding probably by storm waters.

All these deposits show a change in colour from red or orange to pale greens, greys, or yellows as they pass towards the vent. The yellow seems again to be due to the yellow earth found at K06E, but it is here not so abundant.

The sandrock capping the mound is finer than that of the lower series, it does not contain nummulites, and like that at K06E must be regarded essentially as a wind-blown deposit. Dark bands are found in it dipping away on both sides from the crater rim; material exactly similar in appearance was found under dead vegetation in another part.

This upper series is not affected by the slide which itself diminishes in throw as it is traced southward.

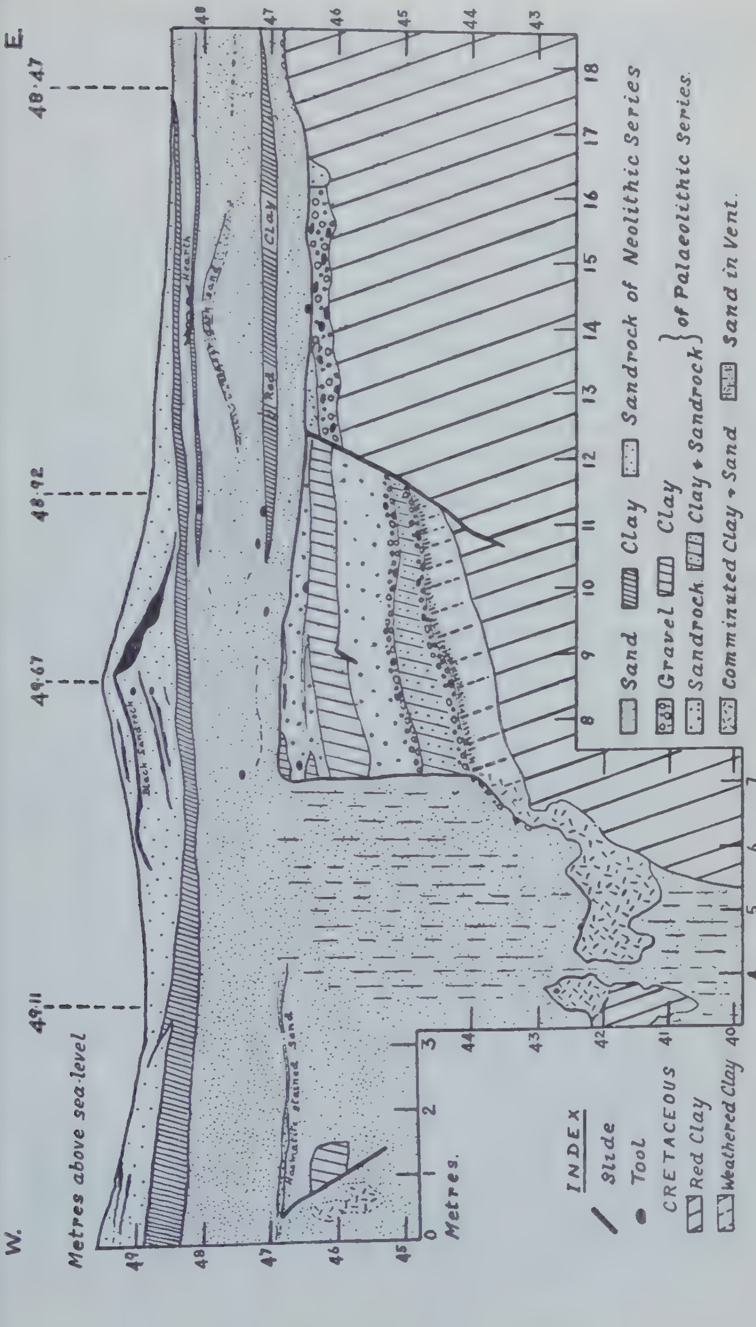

FIG. 10.—Section across Pleistocene Mound Spring, K08A.

Trial pits on the outside of the mound reached bed rock at the following distances and levels from the centre :—

9 metres to the north at R.L. 47·7.
22 „ „ „ west „ R.L. 47·05.
16 „ „ „ „ „ R.L. 44·9.
14 „ „ „ „ not found in a 3½ m. pit.

*The Sequence of Events* at K08A would seem to have been as follows :—

(1) The accumulation of surface wash, largely derived from the neighbouring gravel scarp in a hollow near its base. Middle Palaeolithic man lived on both these surfaces, probably attracted by water from a nearby spring.

(2) The deposits were consolidated, possibly as the result of saturation with water.

(3) A spring broke out in the hollow, truncating the Palaeolithic deposits and causing slipping towards the vent.

(4) Subaerial erosion removed most of the sandrock series from the up-throw side of the fault, and subsequently blown sand with occasional washes of water-laid clays accumulated to a depth of 2–3 m.

Near the vent the sand, damp from capillary attraction, allowed vegetation to become established, thus causing increased accumulation of wind-blown material in this part. Neolithic man lived on or near the mound throughout this period.

This spring is, then, much simpler in structure than K06E, and there are no signs of alternating activity and quiescence ; loams are entirely absent.

The relative small number of springs on the Kharran ridge suggests that the water kept to the same vents for long periods, while the large number and close grouping in the K08 area would seem to indicate that the vents became sealed up as they do in modern springs, the water finding relief of pressure by other outlets.

*Source of Water and Mode of Origin.*

These two questions are intimately connected and will be considered together.

With regard to the water, there are three possible sources of supply :—

(1) Run off and rainfall accumulating in the superficial deposits on the oasis floor ;
(2) the Artesian Water Sandstone ;
(3) the Surface Water Sandstone.

The first would seem to be definitely ruled out by the acid nature of the water (see p. 412). Run off from the scarp and even from the lower slopes would be charged with lime, so also would rain accumulating in the limestone gravels and the dune sands. Yet lime in any form is conspicuously absent in these spring deposits.

Also it is propounded elsewhere (*Geog. Journ.*, 1932) that the run off was never very great, and in those areas where it might have collected (e.g. the low land north-east of Genah) there are no springs, neither do the surface deposits seem sufficiently thick to collect water under considerable pressure. The indisputable evidence of this pressure also rules out one of the commonest causes of springs, namely seepage at a junction of permeable and impermeable rocks such as are found on the depression floor. The springs do not lie along such junctions, though in some cases they are very near them (Text-fig. 6). We have, then, to account for water issuing under pressure through an impervious red clay in a low-lying area. If, as the pressure and position suggest, the water comes from the Cretaceous rocks it must be derived from either or both of the water-bearing sandstones. Now the Surface Water Sandstones according to Beadnell (op. cit., p. 125) contain an abundance of oxide of iron, and hydrous sulphates of aluminium and magnesia; the waters derived from them are, therefore, more or less highly charged with mineral salts. They contain (p. 130) " as much as 63 grains of dissolved solids per gallon, the salts consisting of iron, potash, and soda, with traces of lime and magnesia mostly in the form of sulphates and chlorides ".

The Artesian Water, on the other hand, contains only 30–33 grains of dissolved solid per gallon (430 to 470 per million as against the Kharran analysis of 960). From this it will be seen that the strong probabilities are in favour of the spring water being derived from the Surface Water Sandstones. This conclusion is strengthened by the occurrence of iron oxide around and in some of the mounds.

By what means did the water break through the impermeable covering? An entirely satisfactory answer to this question cannot as yet be given. From the map (Text-fig. 6) it will be noted that west of the main spring line there are signs of disturbance such as vertical and westerly dipping beds. It is possible that the steep west scarp of Gebel-es-Shams is a fault feature; the number of old wells aligned along its edge strengthens this assumption. A fault has tentatively been put in along this line on these grounds and to account for the abnormal lowness of the Cretaceous clays in this area, which on this interpretation would be a small " rift " valley between this Kharran fault and that on the east side of Kharga village.

If the disappearance of the Surface Water Sandstone beneath the red clays to the north of Gebel-es-Shams is really due to pitch, it is possible that the earth-movements which superimposed this southerly direction on the normal easterly dip may have been responsible for the faulting also. We know of earth-movements elsewhere in Egypt in the Pliocene; in Uganda there is evidence of later earth-waves coming in from the north. Is it possible that one of these was responsible for the outburst of the springs? It will be noted on the map that the springs do not lie actually along the supposed fault line, but in K08A there is a distinct suggestion of a linear arrangement in two directions indicated by the broken lines on the plan (Text-fig. 9). It is possible that fracturing or gaping of the clays along these lines may have occurred as a subsidiary consequence of the faulting to the west.

It is of interest to note here that in 1926 an earthquake, severe enough to wreck houses in Alexandria, occurred in the Greek Islands, and immediately afterwards a new sulphur spring appeared at Helwan, 900 km. from the epicentre.[1] On this analogy the earth-movements in Kharga need not have been violent, but it is certain that at the present day no amount of shaking would produce springs from the depleted Surface Water Sandstone. There was, therefore, in Pleistocene times some other factor at work which gave rise to a great increase in the amount and pressure of the water in these rocks. What caused this increase ? For the reasons given above (p. 405) it is extremely unlikely that merely local rain falling on the Surface Water Sandstone outcrops was responsible, and a source further afield must be sought.

Dr. Ball has shown that the underground water of the Libyan desert is probably derived from the rains of the southern Sudan percolating northward along the dip slopes of the Nubian Sandstones.

It is an established fact that the equatorial regions in the Ice Age received more rain than they do at present, and that there were several Pluvial Periods possibly corresponding to the various advances of the ice in Europe. Here then is a means by which both the volume and pressure in the Surface Water Sandstones might have been augmented, and which would, moreover, explain the periodicity of such springs as K06E.

For the present the above suggestions are purely tentative. It is hoped that further work at another group of springs will throw more light on their location, for the fault hypothesis, though satisfactory up to a point, does not explain why springs are apparently absent from the known line of disturbance east of Kharga.

### *Comparison with Modern " Mound " or " Knoll " Springs.*

A close parallel exists between the Kharga fossil springs and the " mound " or " knoll " springs characteristic, at the present day, of arid regions. They are found in the desert valleys of Western America and fringing the Great Artesian Basin in Australia.

In the Tularosa Basin, New Mexico, they are described by O. E. Meinzer and R. F. Hare (10). The form is " a low flat symmetrical dome, at the top of which is a shallow circular depression that may contain water ". The largest is 600 ft. in diameter and 15–20 ft. high, with craters 50–125 ft. across, but there are smaller ones comparable with the Kharga Springs. The mound is a felt-work of vegetable fibres, partly converted into peat, with interstitial black silt, grey gypsum, etc. The vegetation is due solely to the spring water, and once established serves to hold the wind-borne material. In this way the mound grows upward; "when it reaches a height to which water will not rise, the pool is sealed and the water may break out at lower levels in the adjacent plain, with the result that the old mound is drained and a new one begun." The extinct mounds are in the proportion of 3 : 1 to the active ones. They are larger, flatter, and less conspicuous than the active springs, the materials are firmer and oxidation has changed the blue-black colour to a dull red.

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[1] Information kindly supplied by the Director of the Helwan Observatory.

In the active springs the water rises to as much as 10 ft. above the plain, which Meinzer concludes is caused by artesian pressure from a deep source. In some mounds the water lies quiescent as a pool, in others there is a discharge of several gallons a minute, which does not vary with precipitation. The mound springs always lie in low ground, and in some cases the different groups have a somewhat linear arrangement "which suggests a relation to rock structure". According to Meinzer (11) the early stage of a mound spring is a "pool" spring which has a large deep reservoir on top partially covered by an inwardly growing shelf of vegetation. The concretionary network mentioned above (p. 412) might have been something of this nature around a mound spring pool.

The correspondence between the Kharga mounds and the above description is obvious: the shape, the presence of loams, the occurrence of wind-blown sand and traces of vegetation all find their explanation in the modern types. If this comparison is accepted, the climatic conditions must also correspond, which provides a powerful argument for the general aridity of the Kharga floor even in the Pleistocene; though the presence of the clays and derived gravel material at K08A would certainly seem to indicate more frequent and powerful storms.

In Australia the mound springs differ from the Kharga ones in containing travertine among their deposits. They are described by H. Y. L. Brown (12) as "circular mounds of mud, with or without reeds and other rush-like plants, and they are often surrounded by travertine limestone and conglomerate deposited from the water. The water issuing from these boggy mounds forms pools and thence flows away into small creeks which gradually die out as the water becomes absorbed by the soil or is evaporated in the high temperature of this region". We must imagine similar conditions to have obtained around the mound springs of Kharga in Pleistocene times.

But the most instructive feature of the Australian mound springs is their proved association with artesian water. The mound springs occur where the cover of the artesian beds is thin, and du Toit (13) states that "such springs have unanimously been regarded in the light of safety-valves for the relief of hydraulic pressure". These springs are still active, but it is of especial interest to note that extinct mound springs occur in certain areas more than 100 ft. above the present springs. According to R. L. Jack (14) these "point to former much greater escape and greater head due to the existence of intake beds at levels now denuded". Du Toit (op. cit., p. 200), on the other hand, would attribute them most probably to increased precipitation on the Main Eastern Divide during Glacial times, and as this rainfall decreased the springs became extinct (p. 202).

It will be seen that this last hypothesis agrees closely with the suggested cause of the Kharga spring outburst. It is possible that increased area of intake may have contributed to the result, but if so that area lay far to the south, and not on the Kharga floor where, in times past, less, not more, of the Surface Water Sandstones would have been exposed, and where, moreover, the present configuration seems to have been established when the earliest springs broke out.

### *Summary of Pleistocene Hydrography of the Oasis Floor.*

In Pleistocene times the floor of Kharga depression was supplied with water by mound springs, not by a lake or marsh as had been previously supposed.

The springs occur in definite groups all lying in the Cretaceous red clays; the location is probably connected with the rock structure.

A typical spring is a conical mound of sandrock with a crater-like top. The sandrock is a wind-blown deposit, held by vegetation established on the spring; below it are a series of sands and clays and in some cases loams, frequently faulted towards the vent. The latter is marked by great disturbance in the fine sand composing and filling it, and shows evidence of water issuing under considerable pressure.

Oxide of iron, ferric, ferrous, and aluminium sulphate in the deposits indicate that the water was probably derived from the Surface Water Sandstones, and was acid in character. This acidity accounts for the absence of bones, shells, and lime in the deposits. The only signs of life are carbonized reed stems and seeds of *Phoenix sylvestris* Rosch in the loams.

The springs can only be dated by the associated implements. On this evidence they range from Acheulean (late Lower Palaeolithic) to Aterian (Early Upper Palaeolithic). In Neolithic times free flow ceased and holes were dug in the top of the mounds to obtain water.

The outburst of springs is attributed to the increased head of water due to greater rainfall in equatorial regions in Glacial times.

From a comparison with modern mound springs in America and Australia it is argued that the climate of the floor of the depression was mainly arid, though rainstorms were probably more frequent and more violent.

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# Note on the Petrology of the Drybrook Sandstone of the Forest of Dean.

By Brian Simpson, B.Sc., University College of Swansea.

THE late Dr. Vaughan,[1] in 1905, established the age of the sandstone lying above the Whitehead Limestone of the Forest of Dean as of upper *Seminula* age, and not, as had been supposed, as the equivalent of the Millstone Grit. Later, in 1912, Dr. T. F. Sibly [2] described the sandstone as "composed very largely of pure quartz sandstones, often coarse-grained and friable. Conspicuous bands of quartz conglomerate occur: some clays and shales are intercalated with the sandstones: and some haematite deposits are developed". The same author described the structure of the Forest of Dean coalfield [3] and noted the perfect conformity of the

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[1] *Quart. Jour. Geol. Soc.*, 1905, lxi, 251–2.

[2] Geol. Mag., 1912, 417–22.

[3] Geol. Mag., 1918, 23–8.

Drybrook Sandstone on the Whitehead Limestone and the overstep of the Coal-measures. The latest description of the sandstone, and the one which is most complete, is given by Dr. Sibly in his work on the ironstone of the Forest of Dean.[1] His description reads " Red, white, and mottled red and white sandstones compose the bulk of the formation. The rocks are mainly friable, but compact and even quartzitic rocks occur. In the north-east seams of quartz conglomerate are numerous. In the south-west bands of gritty limestone and dolomite develop ".

In the present paper the heavy residues are described, and an attempt is made to lend further support, on petrological grounds, to the age of the series. The specimens were all collected during a field excursion, and are from the northern end of the Forest of Dean, where considerable exposures are seen. In this part of the Forest of Dean, where the structure is seen to be an asymmetric syncline pitching to the south, the thinning out of the Drybrook Sandstone is made apparent; the line of thinning is somewhat obscure, but occurs in the northern portion of Wigpool Common. In this area the limestone is followed, in perfect conformity, by a friable yellow sandstone, representing the base of the Drybrook Sandstone. A section in Scully Grove, at the eastern end of the Forest, shows this junction admirably. The beds of quartz-conglomerate are seen in some old workings, a little to the north of Scully Grove, where quartz pebbles up to 2 inches in diameter are seen embedded in a red sandy matrix. Dolomitic beds are well seen in quarries north of Drybrook.

*The Heavy Minerals.*—The following heavy minerals are recorded from the Drybrook Sandstone and described below—zircon, rutile, tourmaline, apatite, garnet, epidote, muscovite, dolomite, pyrite, and ilmenite.

*Zircon* is by far the most abundant mineral present. Three colours are distinguishable, water clear, purple, and yellow forms. Of the three varieties the colourless forms present good idiomorphic outline. The unit prism and pyramid forms occur most frequently, but deviations from this standard are seen in the development of the bipyramids (311), in the elongation of the crystal parallel to the *c* crystallographic axis, and in the development of multifaced forms which present a general spheroidal appearance. The development of the basal pinacoid and the suppression of the prisms gives a square type which is very common. Rounded forms are the most abundant. The purple zircons are mostly well rounded grains, but a few stumpy square forms have been noted, and in some cases corrosion of the crystal is well shown. The yellow zircons seem to be characterized by elongation parallel to the *c* crystallographic axis in the idiomorphic forms and by fractured anhedral grains. Zoning is apparent in the colourless species, which are sharply idiomorphic, and the concentric appearance is characteristic of the suite. The zones are usually clear and are marked off by dark lines which seem to represent a parting rather than concentrically arranged inclusions. All forms carry inclusions, the most abundant being smaller zircons of the colourless and yellow varieties.

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[1] " Haematites of the Forest of Dean and South Wales : *Mem. Geol. Surv.*, 1927.

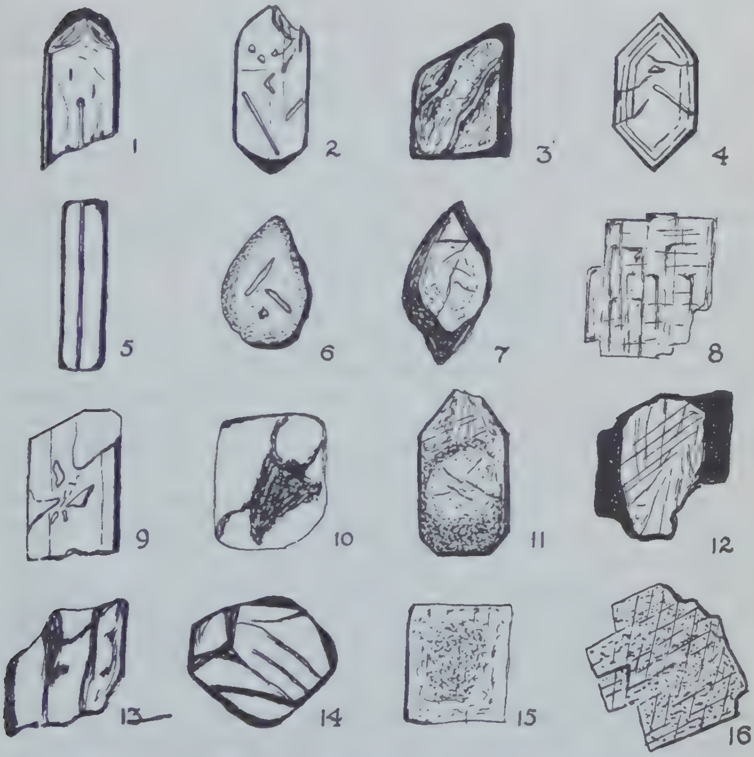


Fig. 1.—1–2. Zircons with idiomorphic form. Note the long rod-like inclusions in 2, and the vacuole in 1. 3. Zircon crowded with magnetite dust. 4. Zircon showing zoning. 5. Elongate form typical of the yellow species. 6–7. Rounded forms typical of the purple variety. 8–10. Tourmalines. 11–13. Rutile. Note the striations on the idiomorphic forms. 14. Garnet. 15–16. Dolomite.

Idiomorphism is usually shown by the inclusions, the elongate forms predominating. Included rutile occurs in very small crystals and occasional geniculate forms are present. Some of the zircon crystals are wholly choked by a mass of opaque dust, the general appearance of which suggests magnetite. In the elongate forms, a central vacuole parallel to the $c$ crystallographic axis is developed, especially in the colourless varieties, and extends throughout the crystal. Cracking is very common, the cracks frequently radiating from the centre of the crystal and being made manifest by the presence of magnetite dust along them. Size is a very variable factor, but the smallest forms observed were 0·06 mm. in length whilst the largest were 0·375 mm., an average being 0·1 mm. (Text-fig. 1, 1–7.)

*Rutile.*—The grains of rutile are remarkable for their large size and anhedral form. In the largest grains observed a length of 0·315 mm. and a breadth of 0·06 mm. was seen, whilst smaller grains of rarer occurrence and with some idiomorphic form have lengths of 0·12 mm. and breadths of 0·045 mm. The idiomorphic form seen in the smaller grains is chiefly the development of the prism and pyramid terminated by the basal pinacoid. Geniculate and the familiar arrow head twins are also present. In colour the mineral ranges from a pale yellow-green to a deep red-brown. The characteristic striation is present on many grains, especially those with idiomorphic outline. (Fig. 1, 12–14.)

*Tourmaline* occurs in two forms; first as well rounded, and secondly as short prismatic detrital grains. Two main types of pleochroism are seen: one, pale russet-brown to deep brown and also, bright blue to colourless. All grains show evidence of much abrasion. Inclusions are numerous, especially magnetite dust, which frequently crowds the whole crystal, and small idiomorphic zircons and tourmalines. (Fig. 1, 8–10.)

*Apatite* is very rare. It occurs in subangular prismatic grains, being clear and colourless, and exhibiting the characters of the normal mineral.

*Garnet.*—This mineral presents good idiomorphic form in many crystals, showing the development of the rhombic dodecahedron; it also occurs in fractured grains. The mineral is clear and colourless and is characteristic of the residues. No etched garnets have been seen. (Fig. 1, 14.)

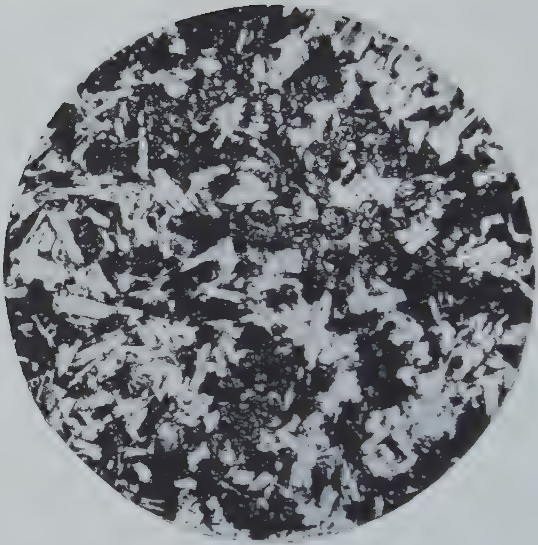
*Epidote* is present in small quantities, occurs in small rounded grains of pale apple-green colour, and is slightly pleochroic.

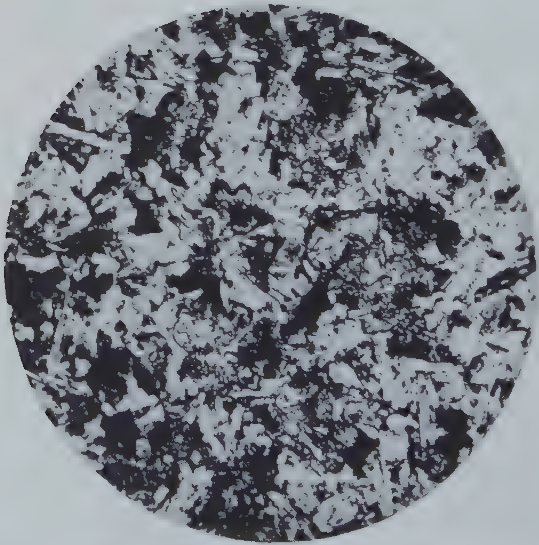
*Muscovite* occurs sporadically in small flakes but is very rare. It displays the characters of normal muscovite.

*Dolomite* in characteristic cleavage rhombs is abundant in some of the more calcareous parts of the series. That it is a secondary mineral is made apparent by the honeycomb nature of the sandstone in which it occurs. It is always colourless and crowded with dark opaque material the nature of which is not apparent. (Fig. 1, 15–16.)

*Pyrite* is present in varying quantities. Some is obviously detrital whilst other portions are not so obviously so. The normal characters of pyrite are displayed.

*Ilmenite* is present in good quantities and frequently shows change to leucoxene.





COMPARISON BETWEEN A QUARTZ-DOLERITE PEBBLE (FIG. B) FROM THE UPPER BROCKRAM OF GEORGE GILL AND THE WHIN SILL ROCK, HIGH CUP NICK (FIG. A).

*To face p. 425.*]

### CONCLUSION.

In conclusion, it has been thought useful to say something as to the comparison of the Drybrook Sandstone mineral assemblage with that of the Millstone Grit of South Wales, the $D_1$ sandy beds of that region, and also with that of the Millstone Grit of the north of England. For the comparison with that of South Wales, Mr. A. Stuart and Mr. F. Pascoe have allowed mention of their unpublished work on the sediments of that region. In the investigation of the Millstone Grit and $D_1$ beds of South Wales the presence of the titanium suite has been noticed, producing a strong rutile-brookite-anatase-sphene assemblage. This suite is absent from the Drybrook Sandstone, a fact which, considering that the beds presumably belong to the same basin of deposition, militates against their identical age. This is still further strengthened by the presence of garnet in the Drybrook Sandstone and its absence in the Welsh Millstone Grit. In comparison with Professor A. Gilligan's work there seems little similarity: the absence of monazite, of blue quartz, and fragments of polygenetic debris of rocks all adds weight to the conclusion that the Drybrook Sandstone is not of the same origin. Finally, although no definite zonal work comes from this study of sediments, yet it does lend support to the palaeontological work which has been done.

The author wishes to express his best thanks to Professor A. E. Trueman and to Mr. Alan Stuart, M.Sc., for help and suggestions in this note.

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# Quartz-Dolerite Pebbles (Whin Sill Type) in the Upper Brockram.

By K. C. DUNHAM, B.Sc., F.G.S., The University, Durham.

(PLATE XXXII.)

THE finding of a small pebble of fine-grained quartz-dolerite in an exposure of the Upper Brockram in George Gill, near Appleby, by Professor Arthur Holmes in 1925 and its identification with the rock of the Whin Sill led to the direct establishment of the time of injection of the Whin Sill and related dykes as post-Carboniferous and pre-Upper Brockram (1928, pp. 532–4). Since 1925 parties of students from the Durham Colleges' Department of Geology have made each year a careful search for similar pebbles not only in the George Gill exposures but in a number of others in the Brackenber Moor neighbourhood. These efforts have not been rewarded with any success until the present year, when a party under my guidance made a thorough examination of the George Gill Brockram and Mr. A. R. Leathley, of Hatfield College, had the good fortune to hammer out a pebble of doleritic aspect.

The conglomerate is exposed in a vertical face about a quarter of a mile above the bridge by which the Appleby-Brough main road crosses George Gill; it forms the south bank of the stream. The present discovery was made in the western part of a low cliff in which small caves have been excavated by the stream; the exact locality is thus very near to that in which the original pebble was found (Westmorland, 6 in. Sheet XV N.E., Lat. 54° 33′. Long. 2° 26′ 15″.).

The pebble is oval in shape and is considerably larger than the one found by Professor Holmes, measuring $9 \times 4 \times 2{\cdot}5$ cm. against $2{\cdot}5 \times 2{\cdot}1 \times 1{\cdot}1$ cm. A crust of much weathered material 2·3 mm. thick surrounds the core, which from its green colour is seen to be somewhat altered. Cracks containing dark limonitic material traverse the rock. Petrographic examination reveals that plagioclase felspar, near labradorite, in laths up to 0·06 mm. long, is abundant. Monoclinic pyroxenes, generally very pale brown in colour, in prisms and irregular plates, make a sub-ophitic texture with the plagioclase. Occasional glomero-porphyritic aggregates of hypersthene-augite occur. Small amounts of a rhombic pyroxene are present together with iron ores, apatite needles and a few shreds of biotite. Interstitial micropegmatite is conspicuous together with an occasional hypidiomorphic individual of quartz. The alteration has resulted in limonite staining and the development of chlorite; it is only a little more intense than that seen in the Whin Sill at its outcrop. A micrometric analysis, using Shand's recording micrometer, shows the percentages by volume of pyroxenes and felspars to be as follows. Measurements made by Professor Holmes (1928) on specimens of the Whin Sill are added for comparison.

| | *Pyroxenes,* P. | *Felspars* F. | $\frac{100\,F}{(P+F)}$. |
|---|---|---|---|
| Pebble, George Gill | 33·1 | 48·4 | 59 |
| Average Whin Sill | 33·8 | 51·2 | 60 |
| High Cup Gill . | 32·6 | 51·4 | 61 |
| Scordale Beck . | 37·8 | 48·3 | 56 |

The foregoing details indicate clearly that both qualitatively and quantitatively there is a striking similarity between the material of the pebble and the normal rock-type of the Whin Sill. The final proof of complete identity is afforded by the accompanying photomicrographs (Plate XXXII) in which B represents the pebble and A the Whin Sill of High Cup Gill.

It remains to consider briefly the provenance of the Whin Sill pebbles. The Upper Brockram consists largely of pebbles of Carboniferous limestones, sandstones and conglomerate, Borrowdale Volcanics and vein quartz. So far as this assemblage is concerned, possible sources are:—

(*a*) The Cross Fell Inlier and the Carboniferous of the adjoining Pennines, as advocated by Kendall (1902, pp. 510–13), Gilligan (1926, p. 27), and Versey (1927, p. 14).

(*b*) The Lake District and its encircling Carboniferous rim, as suggested by Turner (1927, p. 370).

(*c*) The Howgill Fells to the south, as favoured by Trotter and Hollingworth (1928, p. 446).

The work of Wilson and Gilligan (1927) shows that the known igneous rocks of the Howgill Fells area include none remotely resembling the Whin Sill. In the Lake District examples of quartz-dolerite are certainly not unknown, but the types there represented differ markedly in their mineral development and texture from the Whin Sill type. The only source to which the quartz-dolerite pebbles can be referred is, therefore, the Whin Sill itself, either from its exposed edges along the Pennine escarpment or hypothetically from a thin offshoot, now removed by denudation, that may formerly have occurred above the site of Roman Fell or some neighbouring part of the Inlier. Kendall's original hypothesis thus receives support from the presence of Whin Sill pebbles in the Upper Brockram. It is not my intention to discuss further the many views advanced, but simply to point out that an easterly source for some if not all of the Upper Brockram material has been convincingly demonstrated and must henceforth be taken into account in considering the origin of these remarkable beds of conglomerate.

I should like to express my gratitude to Professor Holmes for placing his Whin Sill collection at my disposal and for discussing with me, together with Dr. W. Hopkins, the problems connected with the subject of this note; and to Mr. G. W. O'Neill for preparing the thin sections and the photomicrographs reproduced on Plate XXXII.

## REFERENCES.

1902. Kendall, P. F. "The Brockrams of the Vale of Eden": Geol. Mag., 510–13.

1926. Gilligan, A. "The Geology of the Appleby District." Appleby.

1927. Versey, H. C. "Post-Carboniferous movements in the Northumbrian Fault Block": *Proc. Yorks. Geol. Soc.*, xxi, 1. 1–16.

1927. Turner, J. S. "The Lower Carboniferous Succession in the Westmorland Pennines": *Proc. Geol. Assoc.*, xxxviii, 339–74.

1927. Wilson, A. E., and Gilligan, A. "The Basic Dykes and Sills of the Howgill Fells": *Proc. Yorks. Geol. Soc.*, xxi, 1, 59–70.

1928. Holmes, A., and Harwood, H. F. "The Age and Composition of the Whin Sill and related Dykes of the North of England": *Min. Mag.*, xxi, No. 122, 493–542.

1928. Trotter, F. M., and Hollingworth, S. E. "The Alston Block": Geol. Mag., lxv, 433–48.

## EXPLANATION OF PLATE XXXII.

Magnification × 27. Ordinary light.

FIG.

A.—Quartz-dolerite (No. 553, Professor Holmes' collection), from the Whin Sill of High Cup Gill in the Westmorland Pennines. This is a typical field of the normal variety of the Whin Sill rock, plagioclase, pyroxenes, ores, and interstitial micropegmatite being present.

B.—Quartz-dolerite pebble from the Upper Brockram of George Gill, near Appleby, Westmorland. The field is somewhat darker in colour than that of Fig. A, owing to limonite staining.

# REVIEWS.

RECENT LITTORAL FORAMINIFERA FROM TEXAS AND LOUISIANA. By M. M. KORNFELD. *Contributions from the Department of Geology of Stanford University*, Vol. 1, 3, 1931, pp. 77–93. Plates 4. Price, 7s. 6d.

The author shows in this paper that, on the coast of Texas and Louisiana, there is little difference between the foraminiferal assemblages of the outer shore, and that enclosed by the land bars. The foraminifera, however, become less abundant in embayments, with a tendency to an increase in the proportions of the arenaceous forms over calcareous forms, the reverse of which is true for the open shore-line. The forms described have a long geological range, since several of them are found as far back as the Miocene. The paper is accompanied by two maps and four plates, the latter being good and useful illustrations of the forms dealt with.

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GERMAN-ENGLISH GEOLOGICAL TERMINOLOGY. By A. CISSARZ and W. R. JONES. pp. xvii + 250. London, Murby; Leipzig, Max Weg; New York, Van Nostrand. 1931. Price, 12*s*. 6*d*.

IT is only too true that, as stated in the preface to this book, even a technological dictionary is of very little use to geologists. Their special terms are either not defined at all, or inadequately, while an ordinary dictionary is generally quite hopeless. The plan here adopted is to give a short article defining and explaining the terms, with a close translation into the other language, on the opposite page. This should be extremely useful to students, since it gives an example of the current use of the term in an actual sentence, as well as its meaning, in both languages. The book can be used equally well from either end, so to speak, both English and German. There are two indexes, one in each language. The authors seem to have avoided the complications attached to that tiresome word "Schiefer" by leaving it out. As a matter of fact it is often extremely difficult to make out what a German writer means by "Schiefer" or a French writer by "schiste". This question should really be tackled seriously by geological authorities in both those countries.

# REPORTS AND PROCEEDINGS.

## MINERALOGICAL SOCIETY.

*7th June.*

"Legrandite, a new zinc arsenate." By Dr. J. E. DRUGMAN and Mr. MAX H. HEY. A yellow transparent mineral on a single specimen of blende proved to be a new zinc arsenate. Chemical, optical, goniometric, and X-ray measurements were made. The name legrandite is proposed for the new mineral, the formula of which is $Zn_{14}(AsO_4)_9OH.12H_2O$.

Dr. W. F. P. MCLINTOCK: "On the metamorphism produced by the combustion of hydrocarbons in the Tertiary sediments of south-west Persia." At various localities in south-west Persia the escape and combustion of gas or oil have resulted in the brecciation, partial fusion, and crystallization of calcareous marls with the formation of crystalline rocks consisting of pyroxene (diopside, aegirine-augite, and aegirine), wollastonite, pseudo-wollastonite, bytownite, melilite and leucite, with glass, recrystallized calcite, and anhydrite. In the field the rocks resemble vesicular igneous types, but microscopic examination and chemical analyses, accounts of which are given, prove them in all cases to be metamorphosed sediments.

Mr. F. A. BANNISTER: "On the determination of minerals in platinum concentrates from the Transvaal by X-ray methods (with chemical analyses and syntheses by Mr. M. H. HEY)." X-ray rotation photographs have been used to distinguish and select for chemical analysis the various platinum- and palladium-bearing minerals present in the concentrates of Bushveld platinum ore. The name cooperite is retained for PtS, tetragonal. Synthetic PtS has been prepared and is identical with the mineral cooperite. Laurite ($RuS_2$) occurs in small pyritohedral-cubic crystals and has the pyrite structure. The third mineral $PtPdS_2$, containing about 5 per cent Ni, is also tetragonal. The name braggite is proposed for this mineral, as being the first discovered by X-ray methods.

Mr. JOHN PARRY, Mr. ALPHEUS F. WILLIAMS, and Dr. F. E. WRIGHT: "On Bultfonteinite, a new fluorine-bearing hydrous calcium silicate from South Africa." This new mineral was found in the Bultfontein and Dutoitspan diamond mines at Kimberley and in the Jagersfontein mine in Orange River Colony. It forms pale pink globular aggregates of radiating needles, and has much the appearance of natrolite. Analysis gives the formula $2Ca(OH,F)_2.SiO_2$. From the manner in which the mineral is decomposed by water and by dilute acids, a formula written as $Ca(OH)_2SiO_2.Ca(OH,F)_2$ is suggested. Goniometric and optical examination of the minute crystals shows them to be triclinic, but much complicated by polysynthetic twinning. The mineral is related to afwillite, with the addition of $Ca(OH)_2$ and $CaF_2$, and the nearest ally is custerite $[CaO.Ca(OH,F)_2,SiO_2]$.

Dr. Henry S. Washington has been elected an honorary member.

## CORRESPONDENCE.

### BRIMSTONE HILL, ST. KITTS.

Sir,—Dr. Earle's criticism of our paper on Brimstone Hill does not seem to advance knowledge very far. He might have given us further information regarding the relation of the Godwin Gut limestone to the rest of the volcanic rocks of the island, whether it is in place or has been uplifted. I looked up his list of the mollusca of the raised coral beds on the western side of Dominica and found, as I expected, a number of recent species recorded.

I have more than a suspicion that the western sides of some of these islands have been raised and the eastern side lowered, and this may account for the fossiliferous beds being chiefly on the leeward side. The outline of Dominica is more jagged on the eastern and straighter on the western side, and Curaçao and Barbados have undergone tilting or differential uplift.

I saw no volcanic rocks on St. Kitts which I should care to refer so far back as the early Tertiary, and I attributed the Brimstone Hill mollusc fauna to the Pliocene because it differs appreciably from the living fauna. I left the corals alone, being unable to give any useful opinion on them, but they are in the British Museum (Natural History), where they can be investigated.

Before visiting St. Kitts I was greatly puzzled by the descriptions of Brimstone Hill, as to how a mass of " recent " coral rock could be isolated and uplifted among the volcanic beds, but it did not take me very long to see that the sedimentaries had been dragged up by an extruded plug-like mass of sticky lava and that they were not merely a bit of beach uplifted by a hill of tuff or lava of the Monte Nuovo type. From what depth the sedimentaries have been carried up no one knows, and my suggestion that they may have underlain the main volcano of the island was prompted by analogies with Etna, etc., but remains merely a suggestion.

C. T. Trechmann.

Castle Eden,
Co. Durham.
19*th July*, 1932.

## CRYSTALLINE SCHISTS OF THE MOLDANUBIAN TYPE.

SIR,—Professor J. W. Gregory, in his valuable book *Dalradian Geology* (Methuen & Co., London, 1930), discussing the age of the crystalline schists of various regions, refers to my assumption that the schists and gneisses of the Moldanubian type in Bohemia, in Southern Germany, and the corresponding rocks in France, are Palaeozoic sediments metamorphosed by the Upper Palaeozoic or Hercynian revolution. He states his opinion that my view appears to be "conclusively disproved" by the discovery by L. Zelenka of rolled pebbles of orthogneiss belonging to the gneiss-schist series in the Lower Cambrian conglomerate of Žitec near Przibram, and adds that it has also been rejected by Professor Bubnoff and Professor Kettner.

I feel obliged to reply to this assertion, especially as it concerns a fundamental geological problem, namely, the still disputed question whether the rocks of the highest grade of metamorphism are exclusively Archaean, or whether they may be of later age in certain regions.

L. Zelenka ("Cailloux de gneiss des conglomérats de Žitec (Cambrien inférieur) sur la colline dite Tuškovský vrch", *Vestník státního geolog. ústavu Československé republiky*, Roč. i, 1925, 51), to whom Professor Gregory refers, quotes only *one* specimen from the Žitec conglomerate, one flattened pebble that shows the structure of a crystalline schist. It is described as fine-grained gneiss of dull green colour, containing nodules of metamorphosed felspār, chlorite, muscovite, and plagioclase. Those mineral constituents show characteristics contrary to those of the Moldanubian types, which are biotite rocks containing practically no muscovite. The grade of the Moldanubian metamorphism excludes the occurrence of chlorite in unaltered rocks.

The specimen described by Zelenka is of a very ordinary kind; it could have come from any crystalline region. As rock types that ought to be expected in a conglomerate derived from the Moldanubian Block could be mentioned: biotite-plagioclase-gneiss, sillimanite- and cordierite-gneiss, granulite (in the German sense), amphibolites, calc-silicate-marbles, pyrope-serpentine and many others, but not the rock type cited by Zelenka.

Crystalline schists, as well as granites, have certainly existed on the earth since the earliest geological periods. Pebbles of rocks can be transferred from one geological formation to another and remain comparatively unaltered for an unlimited length of time. Therefore, the above-mentioned pebble affords no evidence that in the neighbourhood of the Cambrian sediments of Bohemia crystalline schists were exposed, as suggested by Zelenka.

Conglomerates and graywackes in which crystalline constituents are entirely wanting are rather rare. But a geologist rambling over the huge stretches of the Algonkian and early Cambrian of Bohemia will be deeply impressed by the fact that the innumerable beds of conglomerate consist exclusively of pebbles of slate, lydite, diabase, spilite, and a few others from the Algonkian itself in astounding monotony, and that crystalline constituents are entirely absent. It appears almost as if at that time no other kind of rocks had been in existence.

Professor Bubnoff, whom Professor Gregory also mentions, only referred to Zelenka's statement, and Kettner, in a paper of 1930 (French resumé : " Sur la position des îlots métamorphisés de la région du massif granitique de la Bohême Centrale," *Zlášţni otisk ze sborníku geologického ústavu Československé republiky*, svazek ix) advocates my view most decidedly when discussing the metamorphic conditions on the border of some islands of Algonkian and early Palaeozoic in the Central Bohemian granite mass. On p. 356 he says : " Il est *absolument exclu* que le *Moldanubien entier*, ou, suivant l'expression de Zelenka qui fait allusion au point de vue de F. E. Suess—la '*zone de tectonique intrusive,*' *soit d'âge antévarisque et antécambrien,*" and on p. 362 he describes an instance of the gradual passage of the Algonkian to the Crystalline.

It is not possible to set forth in this letter the whole intricate question. A discussion from a broader aspect would be necessary. Only a few points may be mentioned.

The Palaeozoic age of the bulk of the Moldanubian granites is proved by aureoles of contact with the Algonkian and the Ordovician. The type of the Moldanubian metamorphism and the structural relations to the granites show clearly that the granite intrusions played the principal part in the development of the metamorphism and that the intrusions were the last and principal factor in the shaping of the structural and metamorphic features of the Moldanubian. The association of the Moldanubian rock types is of such a kind that if restored to their original unmetamorphosed state they would resemble the series of shales, quartzites, limestones, lydites, green schists, diabases, porphyries, etc., that constitute the Palaeozoic region of the Barrandien on the other side of the great Central Bohemian granite mass.

FRANZ E. SUESS.

VIENNA.
*3rd July*, 1932.